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A CASE STUDY OF TWO COMPUTER METHODS USED TO SIMULATE FIRES IN INDUSTRIAL FACILITIES

In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Engineering
at the
Texas A&M University

Submitted by:

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CHAPTER 1
INTRODUCTION

Fire when uncontrolled can create mass destruction. In the movie *Backdraft*, Robert De Niro plays a senior fire investigator who claims to his young eager apprentice that "Fire is a living , breathing, thing that must be treated with respect to understand."[1] Some anthropologists suggest that early humans discovered fire through spontaneous combustion.[2] The arrangement of decaying organic matter may have been enough to generate a small fire. Conventional anthropologists argue that fire may have been first discovered in forest fires started by lightning, lava flows or other natural causes.[2] Fire is real and must be controlled. An area to best control and minimize its destructive effects is during the design process. The design concerns for fire include:[3]

- Control of ignition
- Control means of escape
- Detection
- Control Spread of fire
- Prevention of structure collapse

Prior to controlling the spread of fire one must be able to predict its behavior. One promising method for doing this is with computer modeling. This technology was used by the US Navy in a unique government/industry partnership in analyzing fire in aircraft hangars.[4] With the high cost of modern aircraft, detector and sprinkler activation methods were evaluated to determine a quicker response to small fires with the benefit of reducing damage to aircraft adjacent to the fire source. Along with full scale experiments computer modeling played a role in formulating new approaches.

The computer model should simulate the response of the facility fire control system for the fire. The simulation can be used to evaluate weaknesses in the fire control system. In the long term to make this simulation capability accessible to the architect or engineer from the desk top. Consequently, the user would choose components for parameters to

run a fire hazard scenario and see its predicted results. This capability would particularly be beneficial in the design and construction of nuclear/hazardous waste facilities and shipbuilding . Isolation and the prevention of fire spread are the key to minimizing casualty loss and danger to the surrounding environment.

There are generally two types of computer models, field models and zone models. A field model is two-dimensional or three dimensional that divides the space of interest into thousands of cells, or elements and requires a powerful computer. On the other hand a zone model is primarily one-dimensional and divides the space of interest into a few zones which can be run by a personal computer. Depending upon the detail of the information desired, processing time, and expense either model may be more appropriate.

Two software programs named FIRAC and CFAST were evaluated for the initial steps in formulating a facility response to a fire hazard. This report provides an overview of their capabilities. A brief summary of the two programs is provided below:

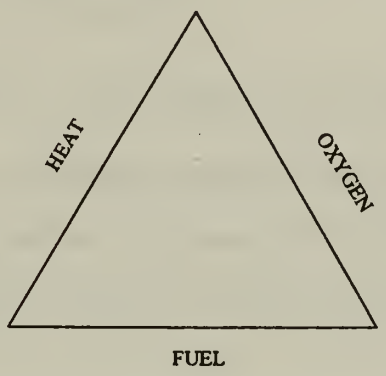
FIRAC- Fire Accident Analysis Computer Code. FIRAC can estimate radioactive and non-radioactive sources to predict fire induced flows within a ventilation system. A flow network is modeled from the building system using nodes and branches. Nodes are connection points for one or more branches. Volume elements such as rooms and plenums are nodes. A branch contains one component such as a duct, damper, or blower. Gas flow pressure differential, and material flow are associated with branches. The maximum problem size is restricted to 100 nodes.

CFAST - Consolidated Fire Growth and Smoke Transport. CFAST can estimate the environment in a multi-compartment structure subjected to a fire. It can calculate the time for the distribution of smoke and fire gases, and the temperature in a building. Contrary to FIRAC which includes an analysis of the ventilation system. CFAST strictly focuses on the effects within rooms and compartments.

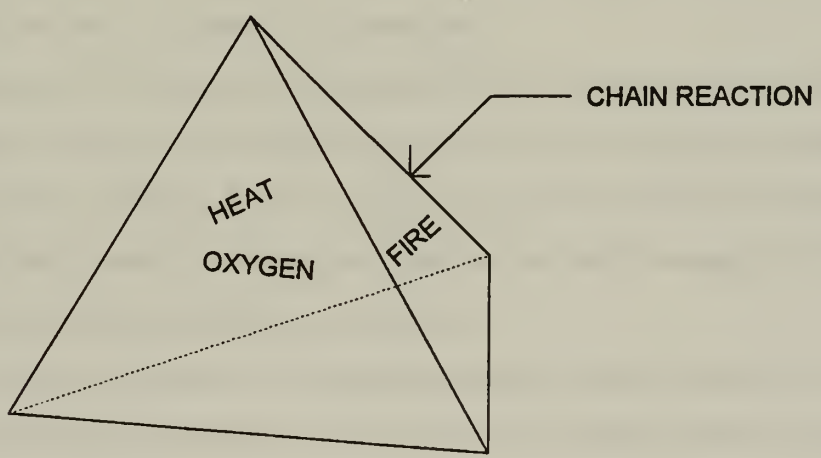
CHAPTER 2

THEORY/BACKGROUND FIRE SCIENCE AND COMBUSTION

For combustion to occur, oxygen, heat and a fuel source must be present. Each of these three components are represented on the fire triangle below:[5]



Taking away one of these components puts out the fire. This triangle can also be extended to a third dimension which represents a fourth support component, the chemical chain reaction between the fuel and the oxidizing agent. This factor is necessary for the fire to support itself and increase in size. It is this chain reaction that propagates the combustion process. Consequently the fire triangle is altered to a fire tetrahedron.[5]



In many instances, fire occurs in a gaseous form that is visible and can vary in appearance depending upon the conditions at initiation. It exists as a display of a chemical reaction between a combustible species and oxygen from the surrounding air. The combustible is a fuel such as wood, gasoline, or plastic. The air is often near standard conditions (25°C) and composition (79% N_2, 20.8% O_2) in industrial/residential facilities. The combustion of methane with oxygen is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{heat and light}$$

The methane molecule is completely oxidized by the two oxygen molecules and heat is given off in the combustion reaction. The carbon dioxide molecule and the two water molecules are in gaseous forms. Light is the visible portion of the reaction that we see as a flame.

A pre-mixed flame is when the fuel is in a gaseous form and already mixed with the oxygen. One common example is a butane cigarette lighter. Conversely, diffusion flames occur as the result of a fuel that is solid or liquid mixing with the oxygen only during combustion. The heat from this combustion causes further decay of the fuel which releases flammable vapors. Just heating an appropriate fuel may not initiate combustion. Combustion occurs when these vapors released by the fuel ignite. If a chemical decomposition occurs it is referred to as pyrolysis.[6]

The flash point is the temperature that the fuel must be heated for the vapors given off to flash when an ignition source is applied. If the fuel is at a temperature when ignition of the gases released is sustained, it is at the fuel's fire point. For the flame to exist at the surface of the fuel the energy released from combustion must be enough to heat the fuel and cause further production of flammable vapors.

The rate of burning of diffusion flames is dependent upon the amount of oxygen, that is mixed with the fuel and the amount of fuel present. In building facilities this amount of oxygen can usually be controlled by varying the parameters for ventilation. Thus it is possible to set a facility response to minimize the burning of diffusion flames. On the contrary this degree of control does not exist for pre-mixed flames which can burn much

faster. However, what may be controlled is the condition for ignition to take place. In addition a pre-mixture of fuel and oxygen in a confined space could be an explosion hazard.

The rate of burning, $\dot{m}$ can be represented as:

$$\dot{m} = \frac{\dot{Q}_F - \dot{Q}_L}{L_V} \tag{1}$$

where: $\dot{Q}_F$ = heat flux supplied by the flame
$\dot{Q}_L$ = losses expressed as a heat flux through the fuel surface
L_V = heat required to produce volatiles

For a liquid, L_v is the latent heat of vaporization. The heat flux, $\dot{Q}_F$, is related to the rate of heat energy release within the flame and heat transfer. Figure 2.1 below demonstrates the applications of the components of equation 1:

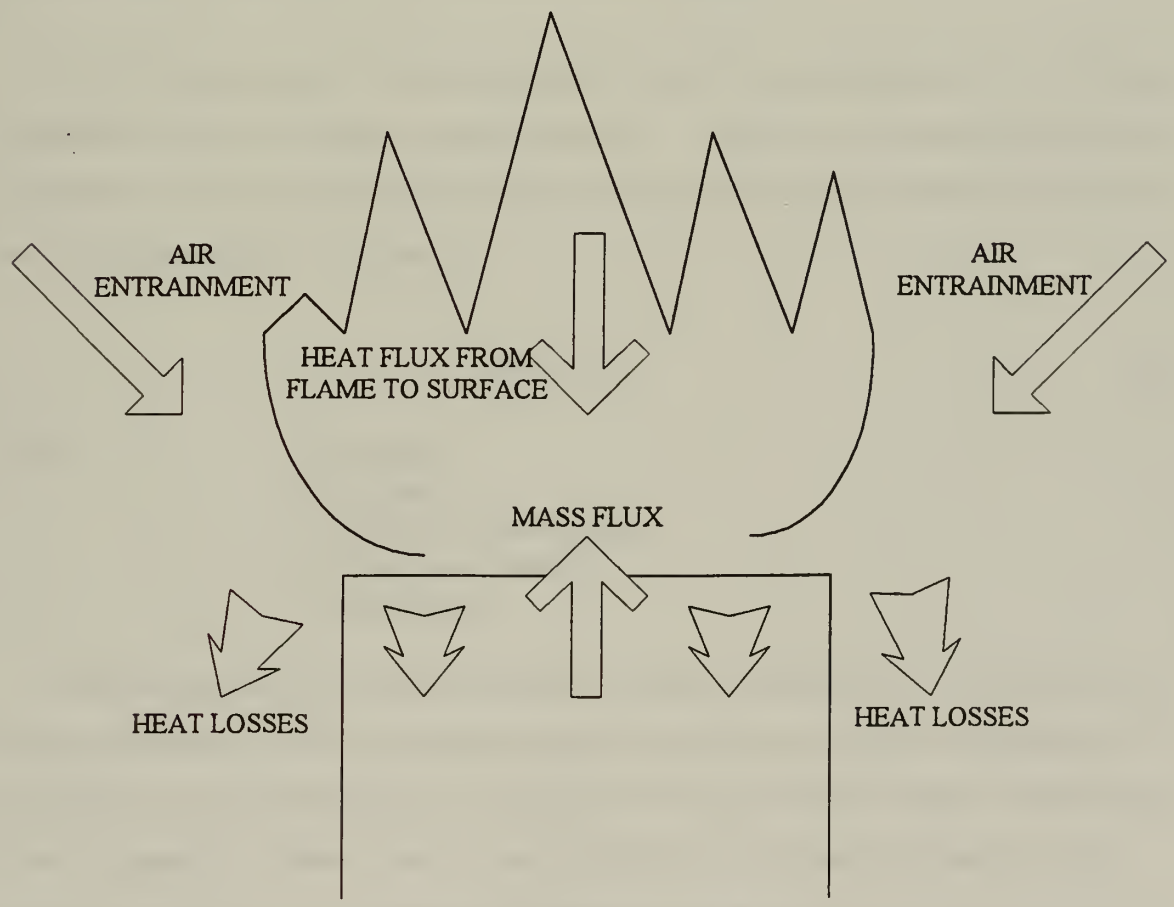


Figure 2.1: A burning surface

When determining the behavior of a fire, the most important factor is the rate at which the energy is released.[6] This energy is expressed by:

$$\dot{Q}_C = X \cdot \dot{m} \cdot A_f \cdot \Delta H_C \qquad (2)$$

where:
X = a factor (<1.0) to account for incomplete combustion
$\dot{m}$ = rate of burning
A_f = fuel surface area
ΔH_C = heat of combustion of the volatiles

Equations 1 and 2 demonstrate that there are many contributory factors which together determine $\dot{Q}_C$ including properties relating not only to the material itself (L_V & ΔH_C) but also to the combustion processes within the flame.

The fire releases energy through both heat transfer from the flames and the products of combustion which are formed at high temperatures. These have a profound effect on the temperature of the surrounding environment. A majority of the products are gaseous and can be modeled with the ideal gas law:

$$PV = nRT \qquad (3)$$

where:
P = pressure
V = volume
n = number of moles of gas
R = ideal gas constant
T = temperature

If the temperature rises while the pressure remains constant, the gas will expand and decrease in density. In a fire the high temperature burning gases and the temperature of the ambient air vary considerably. Compounded with a density differential, strong buoyant flows are generated. These create pressure differentials which are responsible for the drawing of air into the base of the fire. The interactions of the flame and buoyant forces

determine the structure of the fire plume which is the convective column above the source of heat.

In a building fire the three modes of heat transfer (conduction, convention and radiation) are all present in Figure 2.2.

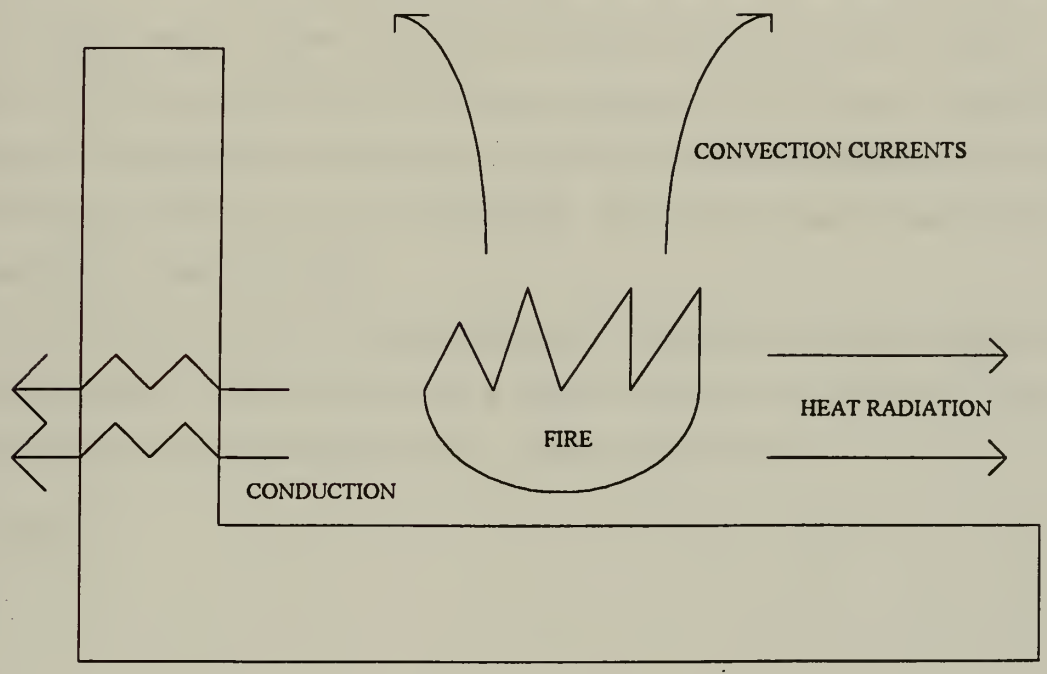


Figure 2.2 Heat transfer in a fire

It is this transfer of heat energy that can cause combustible or flammable materials to ignite even when there is no direct contact with the flame. Conduction is the direct transfer of heat between two substances in contact with each other or through an immediate substance in contact with both substances. Gases conduct heat poorly while solids conduct heat readily. Convection occurs when one substance in a liquid or gas form, circulates between two surfaces, each with a different temperature. There will be a net gain of heat by the cooler of the two surfaces and a net loss of heat by the warmer surface. In a fire, air moves past a hot surface or flame, the air will become heated and rise. As this heated air moves past cooler materials, the air gives up its heat to those materials, which will then increase in temperature and ignite, spreading the fire upwards.

Thermal radiation involves transfer of heat by electromagnetic waves. As a substance is heated it will lose heat partly by convection (if in a fluid) and radiation. Similar to light waves, heat waves are produced and radiate out in direct lines from the heat source. Consequently a combustible or flammable substance can gain heat and will ignite if its ignition temperature is reached.

Depending upon the building configuration and the ventilation available, the three modes of heat transfer can have an effect on sustainment of the fire and the building structure. Fires behave differently in open spaces than closed compartments. A forest fire has little to constrain it except the amount of wood and combustibles present. In contrast the ceiling and walls in a room have an immediate effect of increasing the radiant heat returned to the surface of the fuel.

In an enclosed room with sufficient ventilation a fire will pass through a series of three phases after ignition. These include growth, stability, and decay respectively. [6] Figure 2.3 shows these phases with the heat output of a fire verses time.

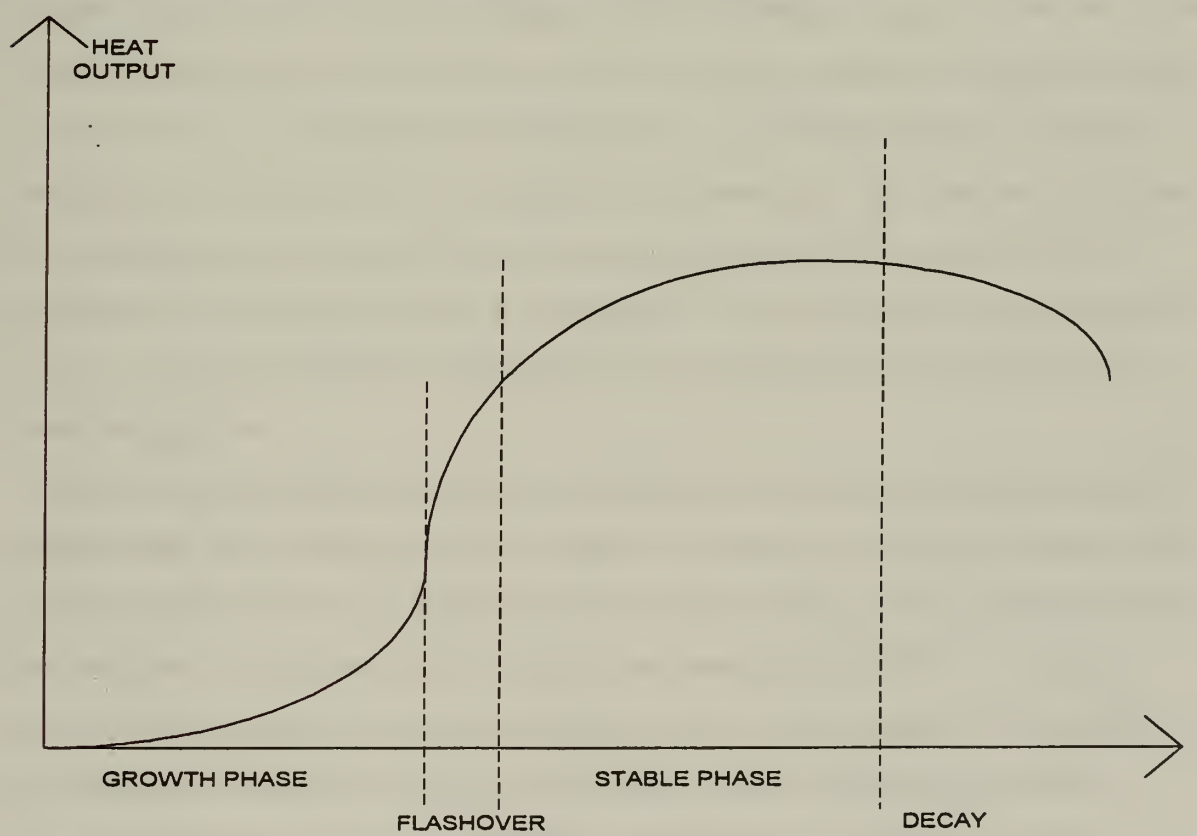


Figure 2.3: Fire phases

The growth period lasts from the moment of ignition to the time when all combustible materials within the compartment are burning. At initiation the vapors given off by the fuel will burn near the surface of the fuel source. Ventilation is ordinarily more than enough to supply oxygen for burning near the surface to take place. As a result, the rate of burning is dominated by the surface area of the fuel. The duration of the growth period depends upon many factors such as compartment geometry and air movement. A critical factor is when the flame reaches the ceiling. As the flames spread out over the ceiling, the radiant heat transfer back to the surface is greatly increased. The remaining combustible materials rapidly reach their ignition temperatures and ignite. This sudden transition is the flashover phase which is also the very beginning of the stable phase.

If there is inadequate ventilation available to the fire during the growth phase, then the fire may not flashover due to an inadequate supply of oxygen. The fire may die out completely, or continue to smolder. This smoldering is very dangerous because with a depleted oxygen supply unburned flammable vapors can begin to collect in the space. In an atmosphere of incomplete combustion, carbon monoxide gas which has an explosive range from 12.5° F to 74° F and an ignition temperature of 1,200° F is generated.[7] Carbon particles are also dispersed in the air (ignition temperature 400° F). Upon entry of oxygen the carbon particles can ignite the carbon monoxide gas and set off a rapid powerful explosion. The phenomenon is known as backdraft. This could happen with the opening of a door. This eruption of flame and/or explosion is so intense it can immediately kill the unsuspecting victim.

During the stable phase, the flaming is no longer localized, but occurs throughout the compartment. The volatiles are mixing with the incoming air, and the rate of burning will be determined by the level of ventilation and the amount of fuel present. It is at this stage that maximum temperature will be obtained, possible as high as 1100° C.[7] In addition, structural damage may occur, perhaps leading to partial or total collapse of the building. The final period of cooling sees the decay of the fire, once all available fuel has been consumed. The rate of burning is dependent upon the fuel and ventilation available. Therefore it is these two factors which determine the heat that will be produced.

It is not only the chemical nature and amount of the fuel which will influence the heat output but the distribution as well. Essentially the greater the surface areas exposed, the greater is the potential for rapid fire development. The proximity of the fuel to the walls and ceiling will also be a factor in determining the fuel spread along these surfaces. The denser the arrangement of the fuel, the longer the fire will take to build up to full heat output, and the longer it will last.

The ventilation of the space where a fire starts will be critical in determining the fire severity and heat output. Both the air supply to the fire and the possible loss of heat by air removal are important. The amount of ventilation will be determined by the shape and sizes of openings such as windows and doors. When the openings are small, the size of the fire may be limited by the amount of oxygen that can be provided. If the openings supply more oxygen than the fire needs, then the rate if burning will be controlled by fuel availability. Increasing the supply of oxygen above that which can be used in the combustion process will serve only to cool the fire as it becomes entrained into the rising smoke plume.

The final factor which has an influence on the fire severity and the rate of heat output is the size of the room in which the fire is burning. A larger area may have more fire potential materials, however, the distance from the fire to the ceiling and the walls will slow down the fire in the initial stages. The slower growth may allow building occupants to extinguish the fire before it spreads. Generally the larger the area, the longer the fire will take to develop, but the fire will be more severe once established.

The majority of fire deaths are due to smoke, either by the inhalation of toxic gases or to carbon monoxide poisoning. Statistics collected in the United States suggests that more than 50 percent of all fatalities can be attributed to the inhalation of particulate smoke and toxic gas (Home Office, National Fire Protection Association, 1997). Smoke is the general term for the solid and gaseous products of combustion in the rising plume of heated air, containing both burned and unburned parts of the fuel along with any gases given off by the chemical degradation of the fuel.[8] The heating of the fuel and the emission of the volatiles will cause a plume of heated gases to rise, and this will entrain air at its base as it rises. Some of the air provides the oxygen necessary to support

combustion. The surplus will mix with the rising combustion products (smoke) and becomes an inseparable element of the smoke. Smoke can also include the induction of radioactive particles which can occur in specialized laboratories.

The appearance of smoke reflects its constituents and will vary from a light color to a deep black. The density of smoke depends on the amount of unburned particles carried in the air. Visibility in smoke depends both on the smoke density and the perception of the occupant. The danger occurs when the visibility is limited and prevents escape. Generally either forced venting a fire to control smoke generation will be necessary or, in the early stages, smoke curtains can be used to form reservoirs and contain smoke.[8]

CHAPTER 3

COMPUTER MODELING A FIRE

ZONE MODELS AND FIELD MODELS

There are generally two types of computer models, field models and zone models. A field model is two-dimensional or three dimensional that divides the space of interest into thousands of cells, or elements and requires a powerful computer. A zone model is primarily one-dimensional and divides the space of interest into a few zones which can be run by a personal computer.

The primary advantage of field model over a zone model is that a field model can provide detailed information on the fluid motions while a zone model cannot, except one dimensionally. If a compartment is irregular such as a long corridor or cathedral ceiling a field model may be required. The advantage of a zone model is its simplicity. This simplicity permits the inclusion of other factors such as facility response, fire suppression, or building evacuation. In addition, scenarios may be run in less time and at a reduced expense.

As an example of a zone model consider a fire in a compartment with a vent. There is an upper zone containing the hot combustion products, a lower zone containing air. A third containing the fire plume, fourth and fifth zones being the walls/ceiling and vent. Equations are written for transfer of mass and energy between these various zones, and solved as a function of time.

SUBMODELS

Submodels are computer codes that take the physical output a step further by calculating the consequences of a fire. These can include structural damage, time for evacuation, and actuation of fire suppression systems.

FIRE SPECIFICATION

Depending upon the parameters of the computer code the fire may be specified in a variety of ways. The simplest being the fire starting at a certain time with a constant rate of heat release, and continuing at that rate for a period of time and then stopping. The next level of complexity is to specify a fire with a heat release rate varying in a prescribed manner with time. More realism is added to the model if the input includes an instruction that the prescribed burning rate is reduced as the percentage of oxygen decreases in the atmosphere surrounding the fire plume. While specified fire data are derived from experimentation most computer codes have default settings for fire depending upon the fuel and surrounding conditions chosen.

OTHER INPUTS REQUIRED

Together with the specification of the fire, the minimum inputs required are:

- geometry of the fire compartment
- thermal properties of the bounding surfaces (ceiling, walls)
- fuel source and location
- ventilation (natural forced, or a combination)

This list can be expanded depending upon the output desired and the code selected for modeling, inputs can further include fire suppression systems, HVAC systems, and egress criteria.

MODEL OUTPUTS

After the model has been provided with inputs, computations can yield many physical outputs verses time:

- temperatures at various locations
- concentrations smoke, oxygen, toxic species
- heat output
- flow rates

The model might then proceed to calculate consequences of these physical variables such as:

- actuation times sprinklers and detectors
- feasibility of escape
- damage to structural elements
- effectiveness of fire suppression systems

Depending upon the type of scenario and the output desired there are numerous software packages available. These will continue to improve with greater application and accuracy with the dramatic improvements to the computer microprocessor.

CHAPTER 4

FIRAC MODEL DESCRIPTION

FIRAC

FIRAC which stands for Fire Accident Analysis Computer Code is a systems computer model that analyzes the effects of a fire on an entire facility. The interconnection of all rooms, corridors, and the HVAC system are taken into account. Since these elements are interdependent the computer code incorporates feedback subroutines to predict over a period of time:

- distribution of pressures
- temperatures
- flows
- smoke - radioactive and gaseous concentration

These results are presented graphically so that the user can visualize concentration (radioactive and gaseous) trends.

The code was developed by the Los Alamos National Laboratory in the early 1980's when mainframe computers were the primary and in most cases, the only means of modeling complex physical systems. The FIRAC User's Manual is based upon running the code via card decks. FIRAC's input deck was divided into ten sections which were: problem control, branch geometry, specie description, boundary node, time function, capacitance node, component, initial conditions FIRIN module and time-step.

FIRAC now has a version which can be run through DOS on a personal computer. Details of running this version are discussed in appendix A which provides a step by step guide for running the problems in the simulation section of this report.

There are three executable files for processing which are FP, FIRAC, and POST. Simulation parameters are input through a graphical preprocessor (FP). The user can pick and choose various elements with a mouse or key strokes and build a systems network. A sample network is shown in Figure 4.1 below.

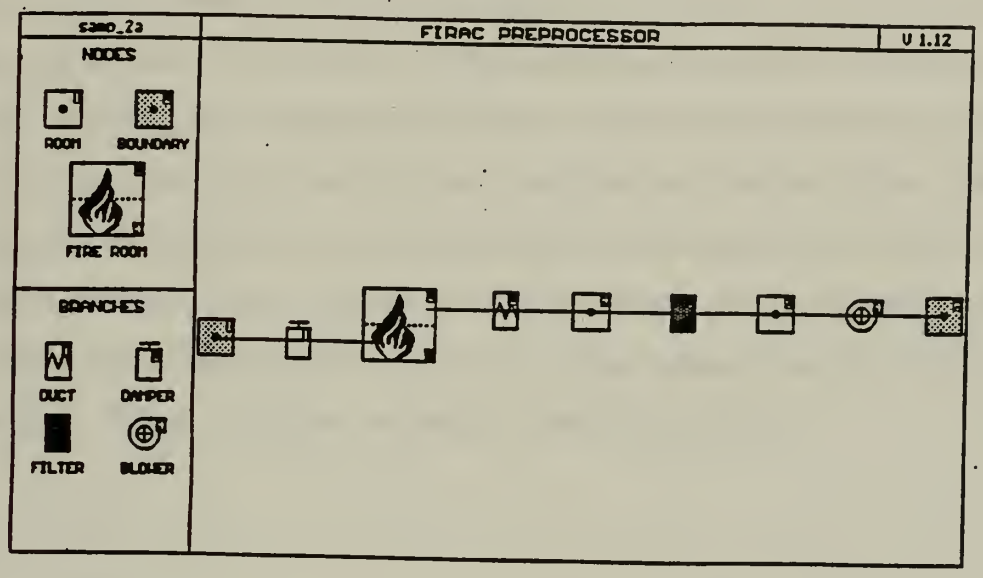


Figure 4.1: System network on pre-processor

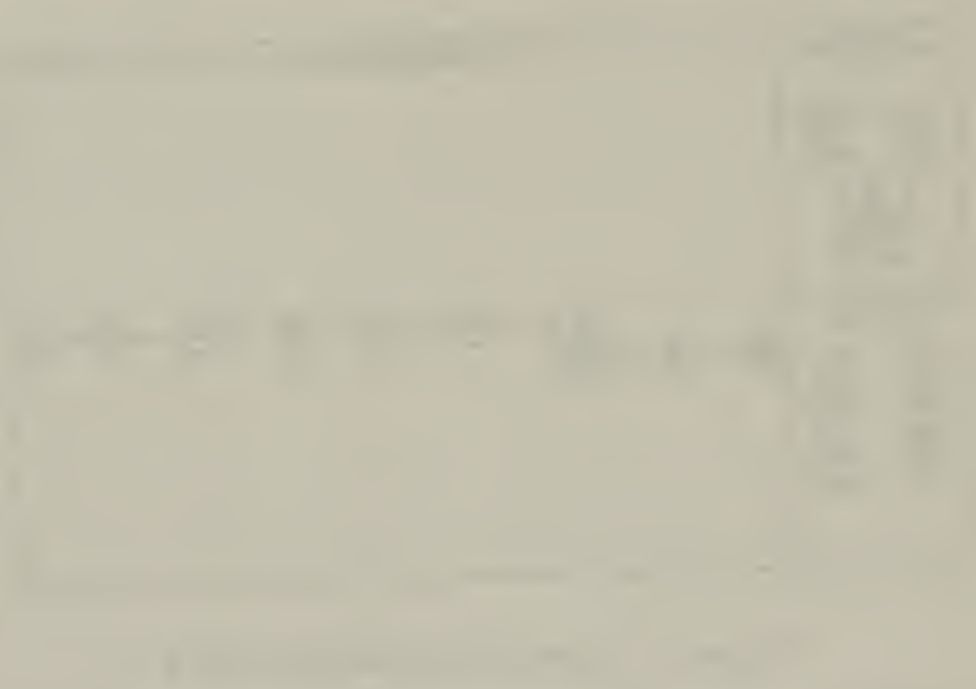
When each element of the network is chosen, the user is prompted with menus for the information required to make a data run. To process input data, the file FIRAC is used. At this time the user is prompted for the input file name created by the pre-processor. Next a name is requested for the output data file. After a run the results can be graphically observed by running the file POST. POST will provide the user with the following graphical presentations:

Node Summary

- Node pressures/temperatures

Branch Summary

- Branch volume/mass flows
- Branch damper angles



The code contains a module named FIRIN which has the capabilities of modeling a zone-type compartment fire model. It is this module that determines the fire compartment conditions. A data base of material properties for several material is available for the fire compartment walls, ceiling, and floor. FIRIN being a zone-type fire model assumes that the gas in the room is divided into two homogeneous layers during a fire. One layer, the hot layer, develops near the ceiling and contains hot combustion products released from the burning material. The cold layer, which is between the hot layer and the floor contains fresh air. Including the compartment parameters, FIRIN predicts the fire source mass loss rate, energy generation rate, and fire room conditions as a function of time. It also calculates the mass generation rate and particle size distributions for radioactive and non-radioactive particles. These particles can become airborne and thus have the potential to contaminate the facility and pose a hazard to building occupants and the surrounding environment. Figure 4.2 shows a schematic of the FIRIN module.

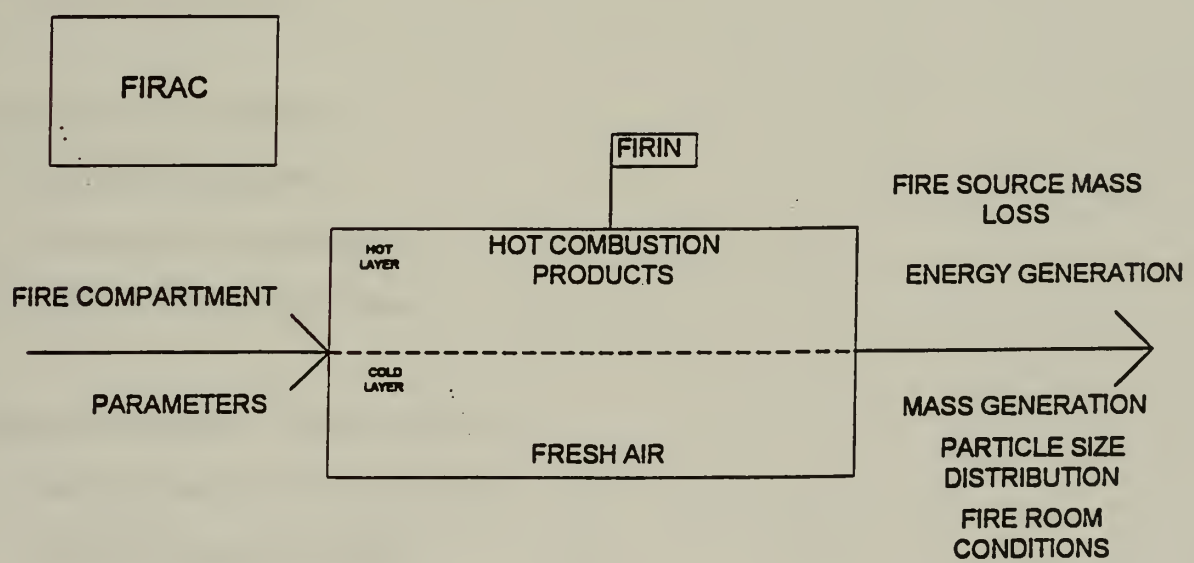


Figure 4.2 FIRIN zone type fire model

FIRIN will provide the user with the following graphical presentations:

Fire Compartment Thermal Effects

- Thermal energy balance
- Mass burn rate
- Hot layer Temperature
- Volumetric flow balance
- Hot layer thickness
- Oxygen volume fraction
- Fire compartment pressure

Particulate Size Distribution

- Radioactive hot/cold layer
- Smoke hot/cold layer

Smoke Source vs. Time

- Smoke accumulation
- Hot/cold layer loss summary
- Hot/cold layer mass balance

Radioactive Source Term vs. Time

- Radioactive source accumulation
- Hot/cold layer loss summary
- Hot/cold layer mass balance

Although FIRAC is still within the development stage for the PC, the current version mirrors the mainframe version. Running a simulation is done in three steps: FP, FIRAC, and POST. Once these steps are started, they must be continued until final completion due to the interdependence of each step.

FIRAC'S PHYSICAL MODELS

FIRAC includes four physical models:

- Gas dynamics
- Material transport
- Heat transfer
- FIRIN fire and radioactive source terms

This section provides a summary of each of the models. A more detailed description is provided in the FIRAC User's Manual.

GAS DYNAMICS

Gas dynamics is modeled by using a flow network. (Figure 4.3)

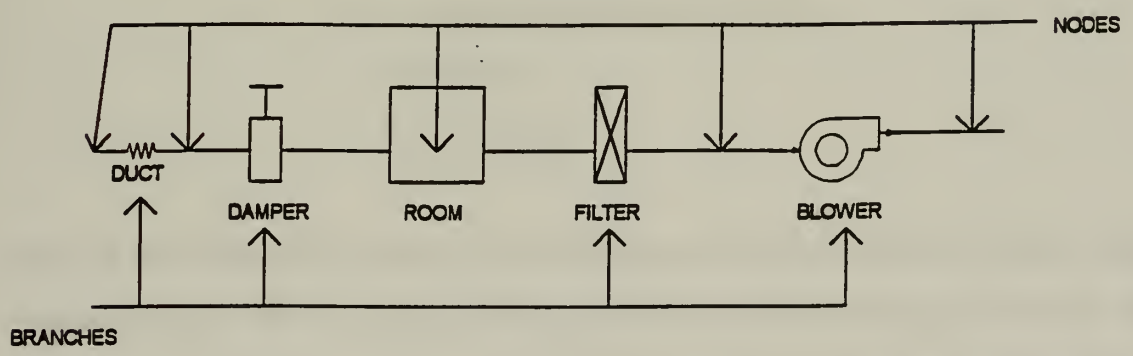


Figure 4.3 Flow network

The flow network consists of two types of components:

- nodes
- branches

A node can either be a boundary node, where the conditions are known (pressure and temperature are known as a function of time) or a room node. Conservation of mass and energy are applied are applied in the room node to determine temperature and mass concentrations. Branches connect any two nodes, and branch models are provided to represent:

- ducts
- dampers and valves
- filters
- blowers, fans

Ducts are modeled using conservation of momentum which includes the effects of inertia, friction, heat transfer, and buoyancy. For high flow rates the momentum equation is replaced by a choking condition. The steady-state pressure drop relationship is:

$$\Delta p = R\rho v^2$$

where: Δp = pressure drop across the duct

R = constant resistance coefficient

ρ = density

v = gas velocity

The code will calculate the value of the resistance coefficient based on the input values of pressure drop and flow. A user specified resistance coefficient may also be used. The resistance coefficients are used to obtain both the steady-state and transient results. Since a lumped-parameter formulation is used in this code no spatial distribution of parameters along the length of the duct is calculated. However, distribution along a duct can further be determined by dividing a duct into smaller sections. A 100 feet length of duct can be

divided into 10 feet sections by inserting room nodes at every 10 feet. Nevertheless, when incorporating this detail, the code's size is restricted to 100 nodes. Heat transfer effects along the length on the duct can be calculated if requested by the user.

Filters are modeled as components that exhibit only resistance to flow. The pressure drop across a clean filter is modeled as a sum of linear and quadratic dependencies on the flow rate:

$$\Delta p_0 = aQ + b\rho Q^2$$

where:

Δp_0 = filter pressure drop

Q = volumetric flow rate

a, b = constants

ρ = gas density

Generally only the linear part of the above equation is applicable to fire situations from which the coefficient a will be calculated from pressure and flow rates. If a more complete equation is desired further input data needs to be supplied by the user from empirical results.

A filter plugging model can be incorporated when there is material accumulation in the filter with an increase in filter resistance leading to a pressure drop. The above filter equation is modified by

$$\frac{\Delta p}{\Delta p_0} = 1 + \alpha M_a$$

where:

$$f(M_a) = \frac{\Delta p}{\Delta p_0} \text{ and } f(M_a = 0) = 1$$

Δp_0 = pressure drop for a clean filter

Δp = pressure drop for dirty filter

M_a = material mass on the filter

α = filter plugging factor, dependent on filter and material properties

The filter plugging factor is input by the user.

Like filters, dampers and valves are modeled as components that exhibit only resistance to flow. The pressure drop across these components is modeled by

$$\Delta p = RQ^2$$

where: Δp = pressure drop

R = constant resistance coefficient

Q = volumetric flow rate

The resistance coefficient can be supplied by the user or calculated by the code.

The model for a blower or fan is essentially dependent on the performance curve of the blower obtained at standard conditions. The code then adjusts the data to predict blower performance at off-design conditions. A number of points are chosen from a blower curve and then input. The code then approximates this curve by straight line segments.

Components that have a finite volume such as rooms, plenums, and gloveboxes are modeled using capacitance nodes or room nodes. The capacitance of the node is represented by its volume. Mass and energy storage are considered by using the conservation of mass and energy equations. The conservation equations are applied to the room nodes using a lumped-parameter formulation which assumes all points are at a thermodynamic equilibrium. As a result spatial details within the nodes are not predicted. An ideal gas equation of state is assumed in the conservation equations. Various combinations of pressure and temperature transient values along with energy and mass sources can specified by the user.

A boundary node is any node for which a pressure and temperature are known. One example is an exhaust opening to the atmosphere. The system layout model must have at least two boundary nodes which serve as boundary conditions. The values of these may be held constant or they may be varied with an input time function.

To represent the fire compartment within the model, two internal boundary nodes are required. It is at the nodes that the module FIRIN is coupled with the system parameters.

The internal boundary node is not treated as a capacitance node but is like a standard boundary node.

Leakage paths from the system to the atmosphere may be approximated by using a boundary node with a fictitious duct.

MATERIAL TRANSPORT

The material transport potion of the code estimates the movement of material in an interconnected network of ventilation system components representing a facility. The code can calculate material concentrations and material mass flow rates at any location within the network. Material transport calculations can be very complex including several different types of materials, changes of phases, chemical reactions between materials, size distributions that vary with time. Simplifying these complexities, FIRAC separates material transport into five components which are:

- material characteristics
- transport initiation
- convective transport
- aerosol depletion
- filtration

Material characteristics and transport initiation are considered by the user. The transportable contaminant material can be any number of aerosol or gaseous species without any phase changes or chemical reactions included. If the material is an aerosol it will be treated as equal sized homogeneous spherical droplets. If the contaminant is a gas then it is assumed inert.

There are three options for material transport initiation which are:

- user-specified
- calculated aerodynamic entertainment
- FIRIN calculated material generation

The user-specified option involves the user supplying material generation rate or mass injection rate (kg per second) vs. time data in the material transport input menu.

The aerodynamic entrainment option is a subroutine designed to calculate aerodynamic entrainment of dry powder from thick beds. It uses flow information from the gas dynamics calculations by taking into account particle, surface, and flow characteristics. The code must be provided with particle size and density, total mass of contaminant, and the floor area of the surface which the powder is uniformly distributed.

The FIRIN module calculates various particulate and gaseous specie generation rates and concentrations for the fire compartment. Up to 13 particulate and 3 gases can be transported by the FIRAC material transport modules. The first two of the 13 particulates are the smoke and total radioactive species particulates. The next 11 can vary from 0.1 microns 20.0 microns. Calculating the transport of material does contribute to the total running time of a simulation thus it is wise to limit the number of species without losing detail.

For convective transport, the model is based on the assumptions that the particle size is small and its mass fraction is small relative to the gas mass in the same volume. As a result it is assumed that the material and the gas form a homogeneous mixture and that they are in dynamic equilibrium. Consequently the presence of airborne material does not affect the gas dynamic portion of the problem

In aerosol depletion, aerosol losses caused by gravitational sedimentation in ducts can be calculated. The algorithm is based on quasi-steady state settling with the terminal settling velocity corrected by the Cunningham slip factor. The flow in ducts is assumed to be well mixed and uniform within the volume. The user must supply the duct height, aerosol diameter and density.

The accumulation of airborne material on the filter can drastically alter the performance which causes an increase in resistance. A linear model is used in which the increase in resistance is linearly proportional to the amount of material on the filter. The proportionality constant is a function of the fuel source and filter properties.

HEAT TRANSFER

The model predicts the exit gas temperature for any section of the duct if the inlet temperature and gas properties are known. These calculations can increase the computer running time by a factor of two. Therefore, it is advisable to apply this capability in actions where it is required such as regions downstream from the fire compartment and particularly in between the fire compartment and any filters. The following heat transfer processes are modeled:

- Forced-convection heat transfer between the combustion gas and the inside duct walls
- Radiation heat transfer between the combustion gas and the inside duct walls
- Heat conduction through the duct wall
- Natural convection heat transfer from the outside duct walls to the surroundings
- Radiation heat transfer from the outside duct walls to the atmosphere

To initiate the heat transfer model, the following inputs are required:

- Equivalent diameter and heat transfer area
- Outside wall emissivity and absorptivity
- Wall density, thermal conductivity, specific heat, and thickness

CHAPTER 5
CFAST MODEL DESCRIPTION

CFAST

CFAST which stands for consolidated model of fire growth and smoke transport is a zone model that analyzes the effect of a fire in a multi-compartment structure. The computer code incorporates feedback subroutines to predict over a period of time:

- distribution of smoke
- distribution of toxic gases
- temperature

The results can be presented graphically so that the user can visualize gaseous concentration trends.

CFAST being a zone model divides a room into two control volumes. These two volumes represent the upper and lower layers of a room subject to a fire. The upper layer which is near the ceiling, is where the smoke and hot gases collect and in time the room is filled from the top. The lower layer contains the fresh air. Although experimentation shows that there is some differences within the layer, the variations are small compared to the disparity between the upper and lower layers. As a result, it is assumed each layer is an homogeneous control volume.

Including the compartment parameters, CFAST solves equations that predict state variables such as temperature and pressure based on the enthalpy and mass flux over small increments of time. These equations are derived from the conservation equations for energy, mass, momentum, and the ideal gas law. This report is intended to provide the reader with an overview and focuses on the operation of the computer code. For an in depth discussion with the derivations outlined consult the CFAST User's Guide.

CFAST treats fire as a source of fuel which is released at a specified rate. Through application of the heat of combustion this release is converted into enthalpy. It is also converted into mass by the yield of the particular species as it burns.

One source for moving enthalpy and mass between the layers within a room, and between rooms is a plume. Above any burning object, a plume is formed which is not considered to be a part of either layer, but which acts as a pump for enthalpy and mass from the lower layer into the upper layer. The second source is the mixing between the layers which occurs at vents such as doors or windows. At these locations there is mixing at the boundary of the opposing flows moving into and out of the room. Both the outflow and inflow entrain air from the surrounding layers. The flow at vents is modeled as a door plume and uses the same equations as the fire plume, with two differences. First, an offset is calculated to account for entrainment within the doorway. Second, the equations are modified to account for the rectangular geometry of vents compared to the round geometry of fire plumes. All plumes within the simulation entrain air from their surroundings. Entrained air can add oxygen to the plume and allow burning of the fuel. It also causes it to expand from a cylindrical shape to an inverted cone as the air plume moves upward.

As discussed earlier, each room is divided into two layers, the upper and lower. At the start of the simulation, the layers in each room are initialized at ambient conditions and by default, the upper layer volume set to 0.001. This is to avoid a division by zero condition. As enthalpy and mass are pumped into the upper layer by the fire plume, the upper layer expands in volume causing the lower layer to decrease in volume and the interface to move downward. If the door to the next room has a soffit, there can be no flow through the vent from the upper layer until the interface reaches the bottom of that soffit. Thus in the early stages the expanding upper layer will push down on the lower layer air and force it into the next compartment through the vent by expansion.

Once the interface reaches the soffit level, a door plume forms and smoke flows from the fire room and fills the second room. Consequently, the lower layer of air in the second room is pushed down. Some of this air flows into the fire room through the lower part of the connecting doorway or vent. Thus, a vent between the fire room and connecting

rooms can have simultaneous, opposing flows of air. All flows are driven by pressure differences and density differences that result from temperature differences and layer depths.

VENT FLOW

There are two kinds of flows through vents: horizontal and vertical. Horizontal is the flow through doors and windows. Vertical flow can occur if there is a hole in the ceiling or floor of a compartment. This flow is particularly important such as in ship overheads or when fire fighters cut holes in a roof to vent a fire.

Pressure difference controls the flow through a vent. There are two situations which give rise to flow through vents. The first is that of air or smoke which is forced from a compartment by buoyancy. The second type of flow is due to expansion which is particularly important when conditions in the fire environment are changing rapidly. Rather than depending entirely on density differences between the two gases, the flow is forced by volumetric expansion. In most cases the differences are small except for rapidly changing situations. However, these small differences become very important if we wish to follow flows due to small pressure differences, such as will occur in an HVAC system.

HEAT TRANSFER

The gas layers in a fire exchange energy with the surroundings by heat transfer. Convection occurs from the layers to the room surfaces. The enthalpy thus transferred in the simulations conducts through the wall, ceiling, or floor in the direction perpendicular to the surface only. CFAST allows different material properties to be used for the ceiling, floor, and walls of each room. However, all walls must be the same material composition but may contain up to three layers of different materials. This allows the user to deal more realistically with the actual building construction. Since the material thermophysical properties variation is relatively small with temperature, they are assumed constant.

However, mechanical properties such as strength could change considerably even to early failure are not modeled.

Heat transfer by radiation occurs among the fire, gas layers and compartment surfaces This transfer is a function of the temperature differences and the emissivity of the gas layers as well as the compartment surfaces. For the fire and typical surfaces, emissivity values only vary over a small range. For the gas layers, however, the emissivity is a function of the concentration of species. Any error in the concentration determination could detrimentally effect the room predictions.

SPECIES CONCENTRATION AND DEPOSITION

At the start of the simulation the layers have the following ambient conditions:

- oxygen 23% by mass
- nitrogen 77% by mass
- temperature, set by the user
- water mass concentration, set by the user
- zero concentration for all other species

The various species are produced in direct relation to the mass of fuel burned. Each unit mass of a species produced is carried in the flow to the various rooms and accumulates in the layers. The model keeps track of the mass of each species in each layer, and knows the volume of each layer as a function of time. The mass divided by the volume is the mass concentration, which along with the molecular weight gives the concentration in volume percent or ppm as appropriate.

FASTlite

A software package named FASTlite which stands for Fire Growth and Smoke Transport incorporates the code CFAST to provide predictions of fire phenomena for the

architect and engineer. The software can be run on a personal computer of the 386 type and up. Fastlite is a step towards running fire simulations from the desk top.

The software is user friendly with a menu driven graphical interface capability. Following the installation of the software the user can select the size and composition of up to three adjacent compartments with the click of a mouse. In addition, fire suppression systems can be added to see their effects. The compartments can be connected by both horizontal and vertical doors or windows.

Once the structure has been selected the fire is specified. For a wide range of fires the fire growth can be represented with the relation:

$$Q \propto \alpha t^2$$

where: Q = heat release of the fire

α = fire intensity coefficient

t = time

The user is then given a set of specific T - squared fires labeled:

- slow - fire reaches 1000 BTU/s in 600 seconds
- medium - fire reaches 1000 BTU/s in 300 seconds
- fast - fire reaches 1000 BTU/s in 150 seconds
- ultra-fast - fire reaches 1000 BTU/s in 75 seconds

or a predefined fire can be input by the user. To aid the user in creating a pre-defined fire a data base is available containing a variety of fuels.

The simulation can be initiated from the same screen as the parameters were input from. Once the simulation is begun graphs are presented showing upper layer temperature, layer height and heat release rate all with respect to time. The graphs are

updated in real time so the effects of modifications to problem parameters can be witnessed immediately. Contrary to FIRAC, Fastlite allows the simulation to be halted and started from the same moment to make changes such as opening a door. The effects are shown immediately with the capability to model a backdraft which will be the scenario modeled in the simulation section.

CHAPTER 6

FIRAC SIMULATIONS

Two primary simulations were performed to illustrate most of the capabilities of the FIRAC code. The first concentrates on the modeling and predictions encountered in a single room with a fire. The second is a section of a facility network. The step by step procedures for inputting the data and running the FIRAC program are included in appendix A for the potential user.

FIRST SIMULATION

The single room where the fire is to take place has dimensions of 16' X 13'X 12'. The floor, walls, and ceiling are 1 foot in thickness composed of concrete. The fuel source is 2.0 lbm of kerosene with a surface area of 5.0 ft^2. A schematic of the room is shown in Figure 6.1. The room has an initial temperature of 60° F with an initial pressure of 14.7 PSIA. The simulation is run for 500 seconds. The kerosene is ignited at time zero.

To input these parameters into FIRAC, the room was constructed with two boundaries (inlet and exhaust). The components are shown in Figure 6.2.

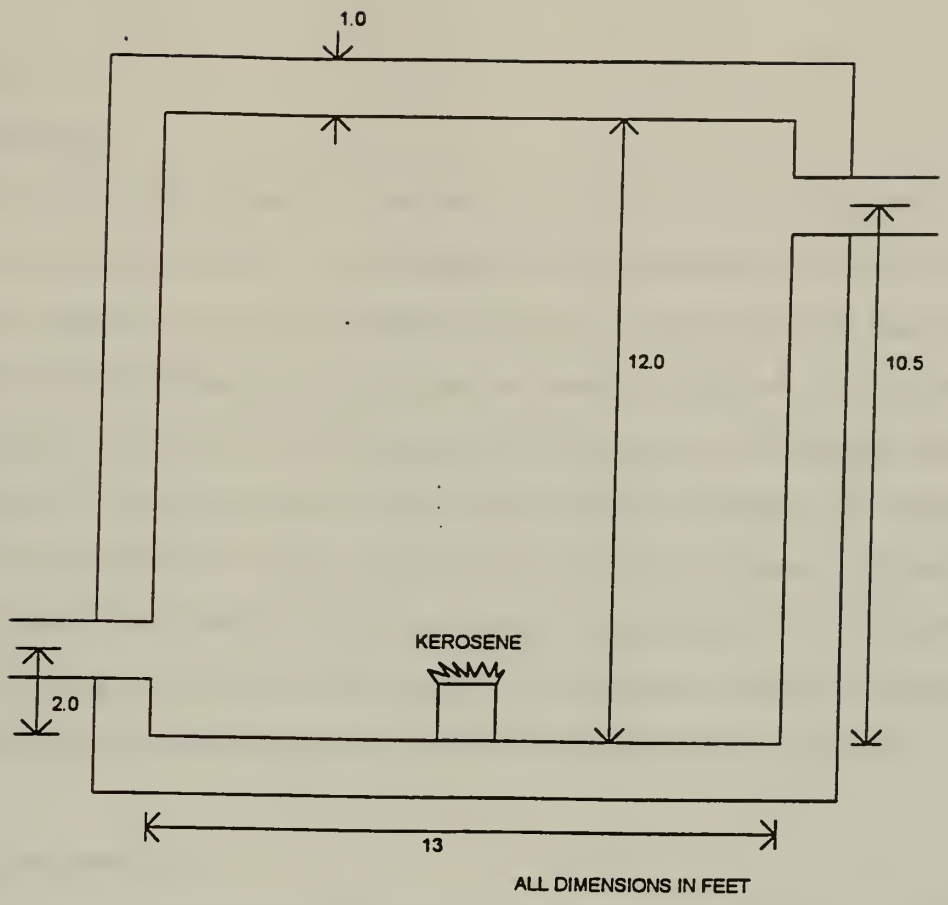


Figure 6.1: Schematic of room

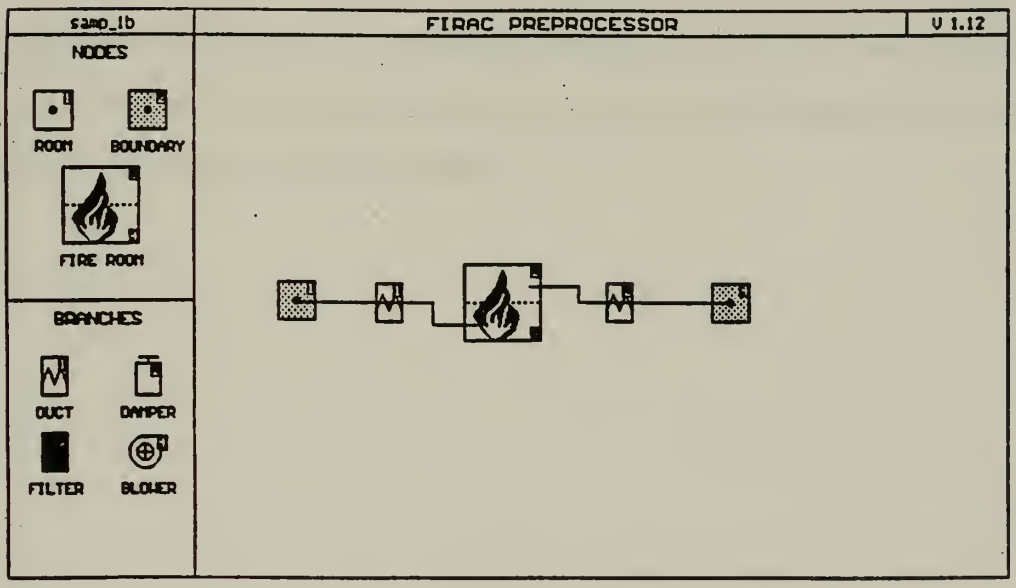


Figure 6.2: Components for the FIRAC pre-processor

RESULTS

Temperature

Figure 6.3 is a graph of the hot layer temperature which shows an instantaneous maximum temperature of 400° F. The change in room temperature from 60°F to 400°F is instantaneous since the kerosene is ignited at time zero. This rapid growth phase is short lived due to the flash of flame occurring when the kerosene is ignited. The temperature then decreases to about 232° F at 90 seconds into the simulation. During this time the fuel is at an even burn. The vapors given off by the fuel sustain the ignition. The temperature of the hot layer stabilizes for a short period of time of about 50 seconds. Concurrently, the mass of the fuel is expended which has a dramatic decreasing effect on the flame size and corresponding temperature of the hot layer. The temperature begins to decrease approaching the initial room temperature of 60° F when all the fuel is depleted.

Smoke accumulation

Smoke is the gaseous products of burning organic materials in which small solid and liquid products are suspended in the air.[6] The smoke accumulation shown in Figure 6.4 steadily approaches 0.167 grams. If the simulation were run longer the amount would increase to a point until fuel depletion since the room has two boundaries and no external force such as a blower to exhaust the smoke.

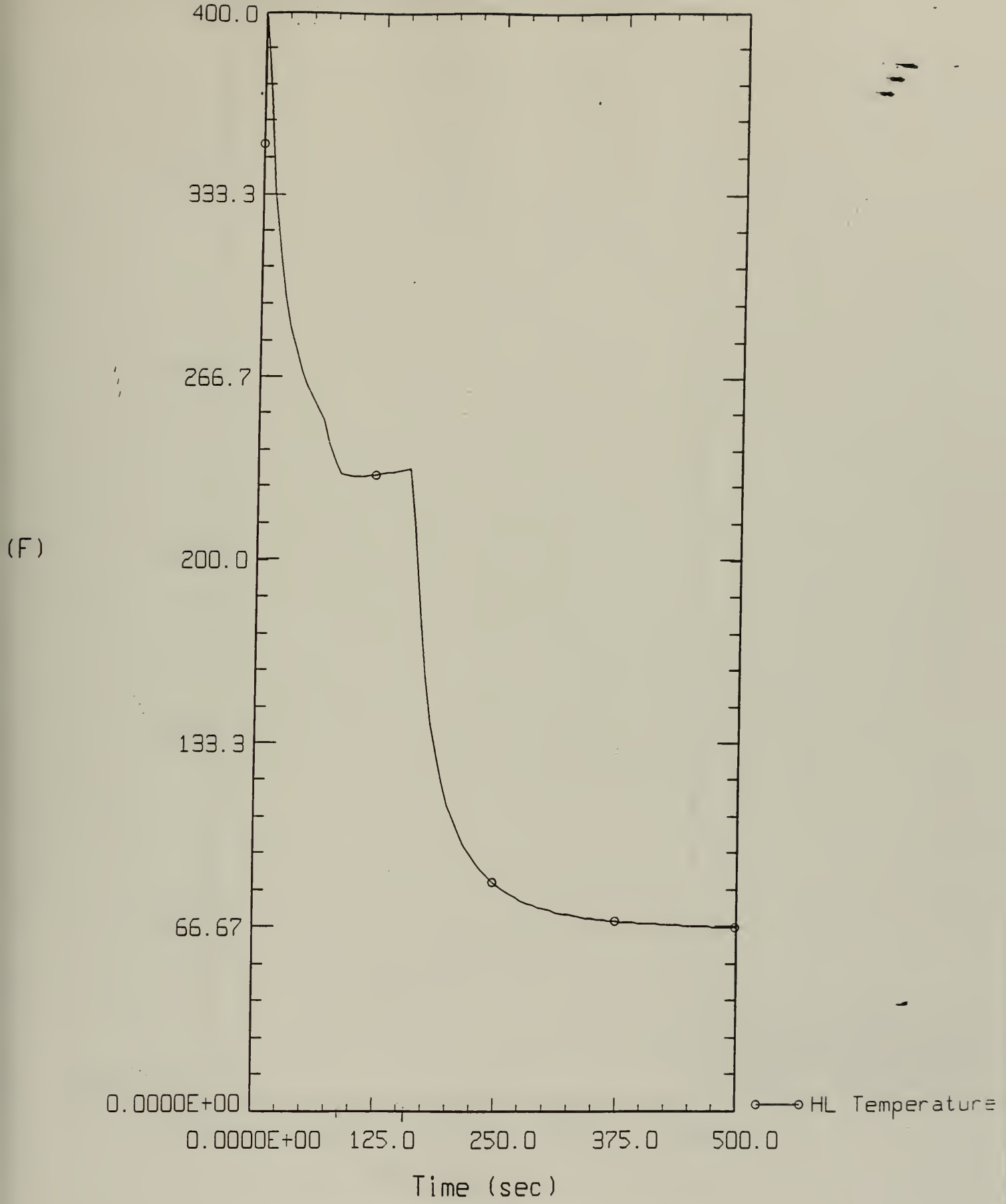


Figure 6.3: Hot layer temperature with one container

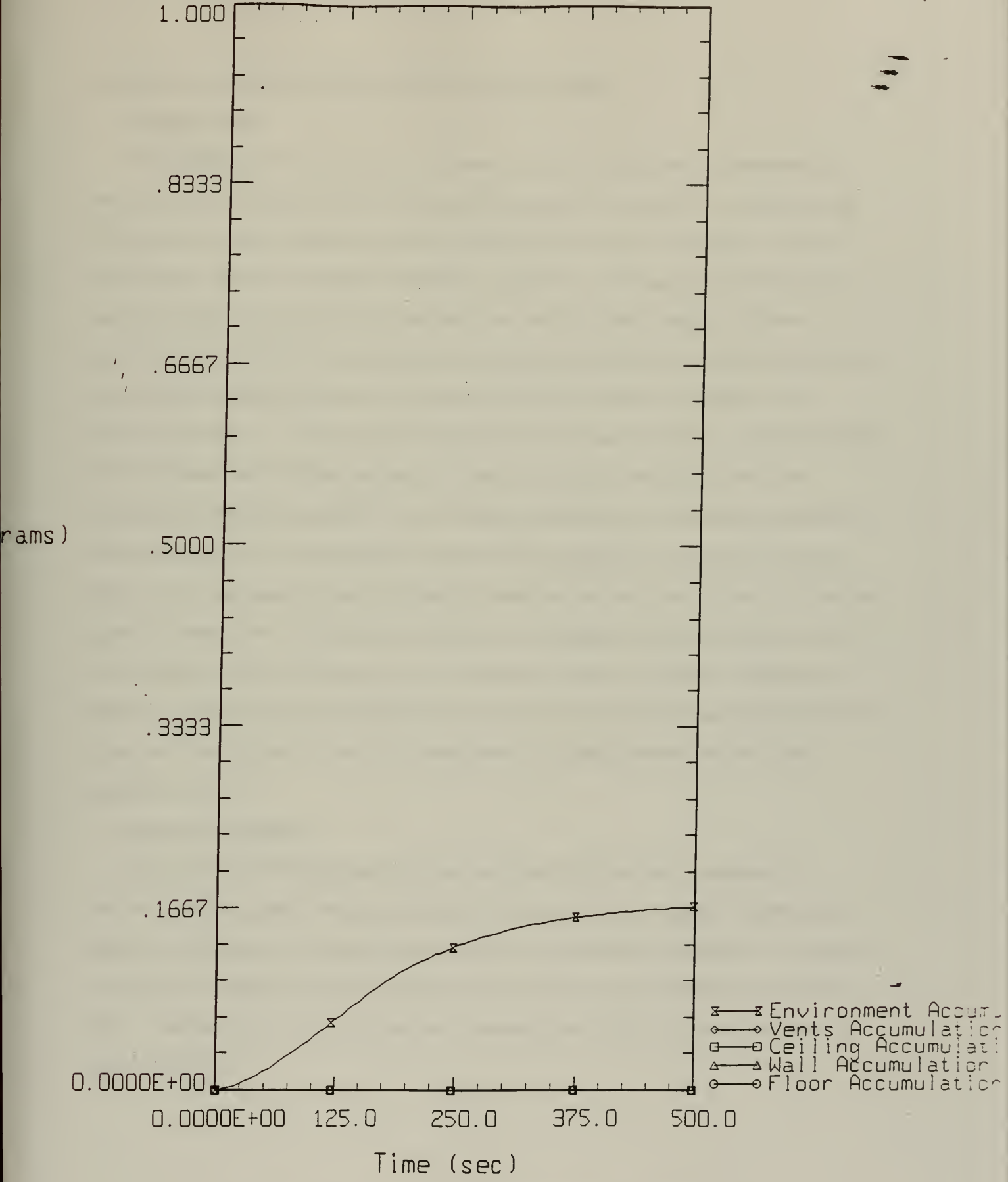


Figure 6.4: Smoke accumulation with one container

ADDING A SECOND CONTAINER OF KEROSENE

Temperature

The simulation was run again for 500 seconds with the same room parameters and initial conditions except a second container of kerosene was added for a material at risk. The second container was twice the size of the first with 4 lbm of kerosene a 10 ft^2 of surface area. The first container was ignited at time zero. The second container being a material at risk was ignited by the heat and flame from the first container. Figure 6.5 shows the dramatic effect on the hot layer temperature prediction. For the first 90 seconds the hot layer temperature mirrors the prediction with one kerosene container in the previous simulation. At about the 90 second mark the second container is ignited from the heat and flame from the first resulting in a drastic increase in temperature with the compartment approaching 560° F. In the previous simulation the maximum temperature obtained was 400°F. In this simulation, the hot layer temperature shows the combined effect of two containers burning. The second container has twice the surface area, thus has a greater flame spread with more heat released. As expected the hot layer begins to cool off much later, almost 75 seconds later, since there is more fuel present which takes longer to expend. As the fuel is depleted a decrease in flame size and heat released leads to a decrease in temperature. The room temperature then finally approaches the initial condition of 60° F.

Smoke accumulation

A larger amount of fuel present and the combined effects of both containers of kerosene, create a greater smoke accumulation value and rate. Looking at Figure 6.6 the smoke accumulation slope is much steeper with an accumulation climbing to 0.566 grams. An increase of almost four times compared to the previous accumulation value of 0.167 grams. This change in slope occurs at the 75 second mark when the second container is ignited by the first.

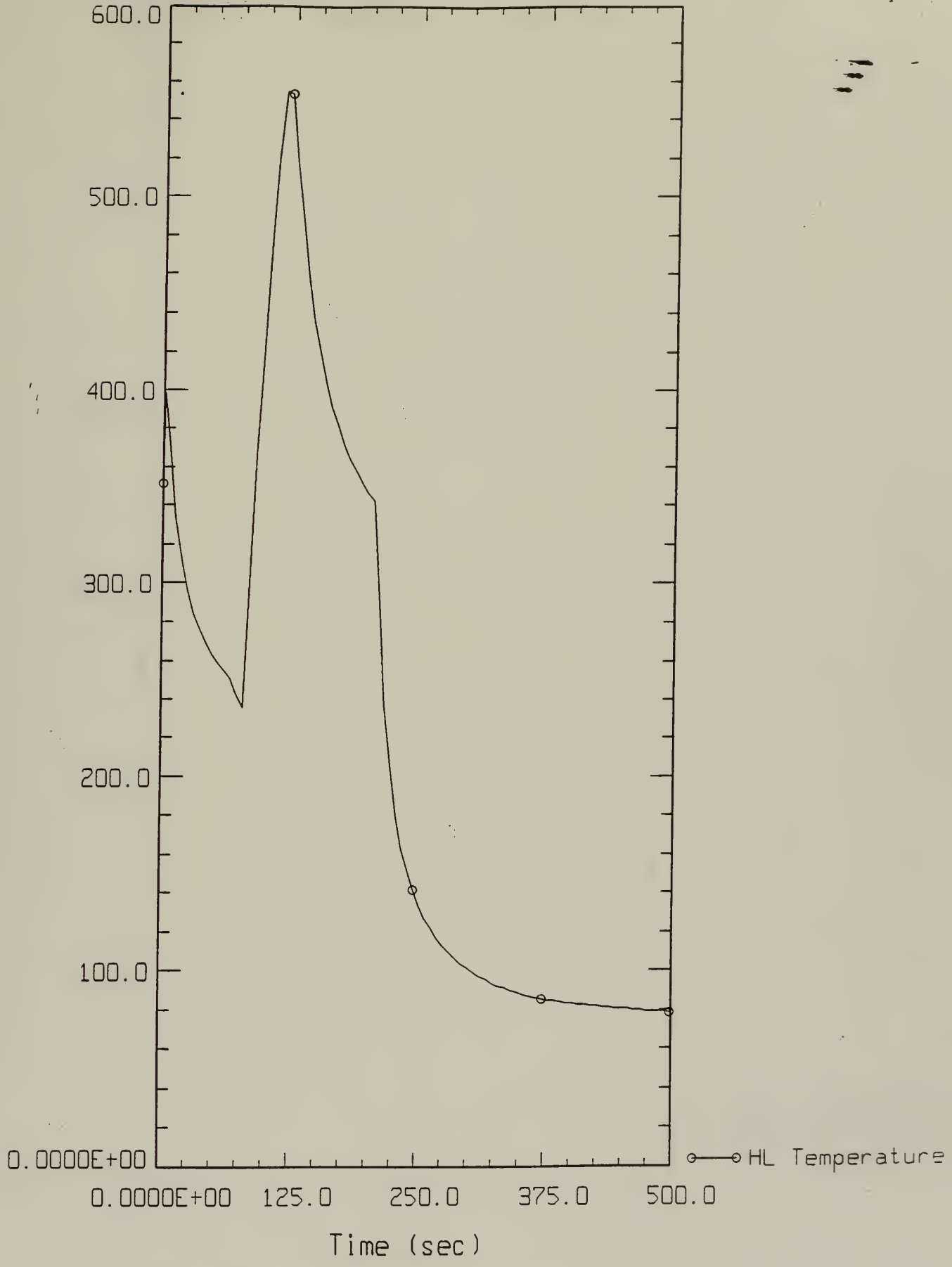


Figure 6.5: Hot layer temperature with both containers

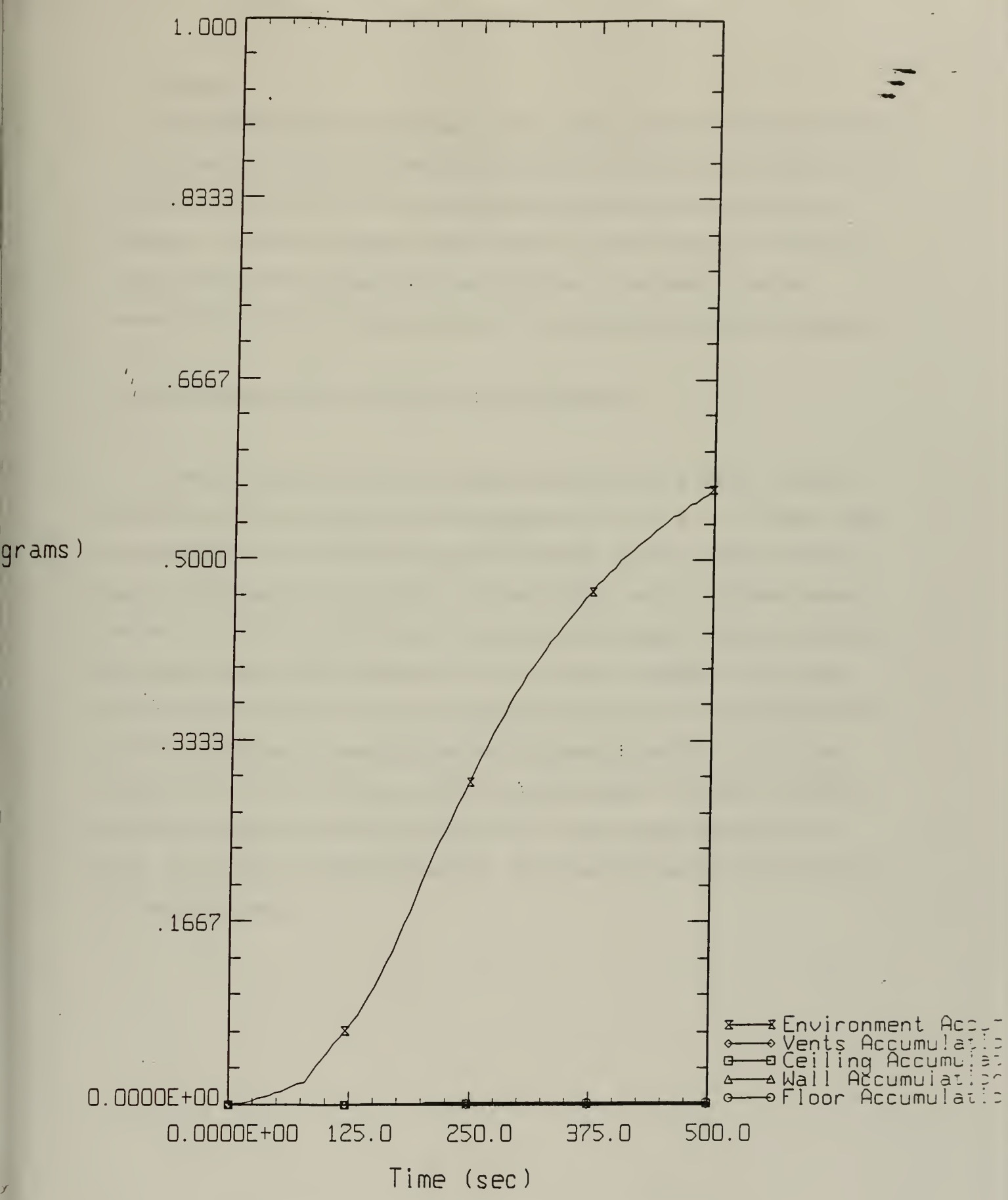


Figure 6.6: Smoke accumulation with both containers

Summary

As described earlier the concentration of the previous simulation was the effects in the fire compartment. Both the inlet and outlet boundaries were at ambient conditions of 60°F and standard pressure of 14.7 PSIA keeping the dynamic effects of the problem to a minimum. The impact of adding a second container of volatile material was taken into account with a greater maximum value and sustainment of temperature. Smoke accumulation was almost 4 times as great with the combined burning of both containers.

SECOND SIMULATION WITH DYNAMIC EFFECTS

The second simulation illustrates the dynamic effects within a facility. The single room where the fire is to take place has dimensions of 16' X 13' X 12'. The floor, walls, and ceiling are 1 foot in thickness composed of concrete. The fuel source is 2.0 lbm of kerosene with a surface area of 5.0 ft^2. Connected to the room is a ventilation network with an inlet and outlet. The inlet has 2 feet of duct with a damper. The outlet duct is 10 feet long containing a HEPA filter and a 750 CFM blower. A schematic of the room layout is shown in Figure 6.7. Figure 6.8 shows the systems network constructed on the FIRAC pre-processor. Located upstream and downstream of the filter are two room nodes (nodes #4 & #5) to observe predictions in those sections. The single room where the fire takes place has an initial temperature of 60° F with an initial pressure of 14.7 PSIA. The simulation is run for 500 seconds. The kerosene is ignited and the blower is activated at time zero.

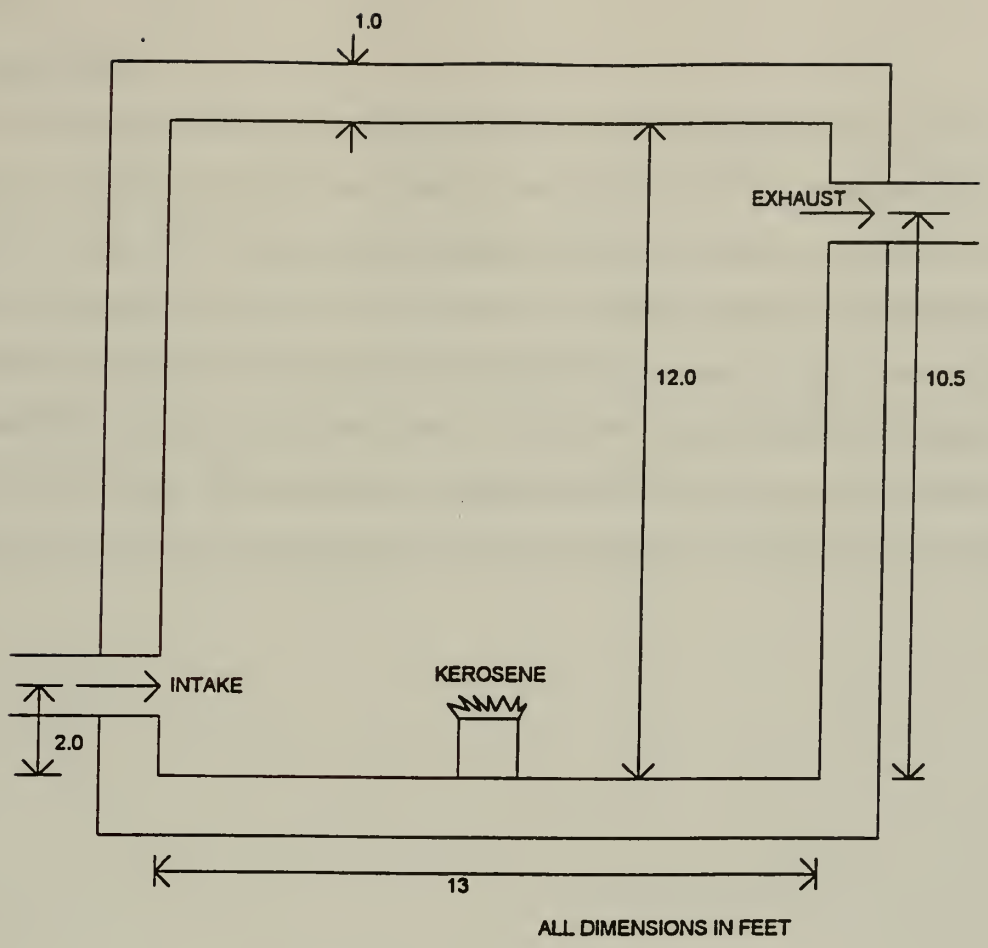


Figure 6.7: Schematic of room

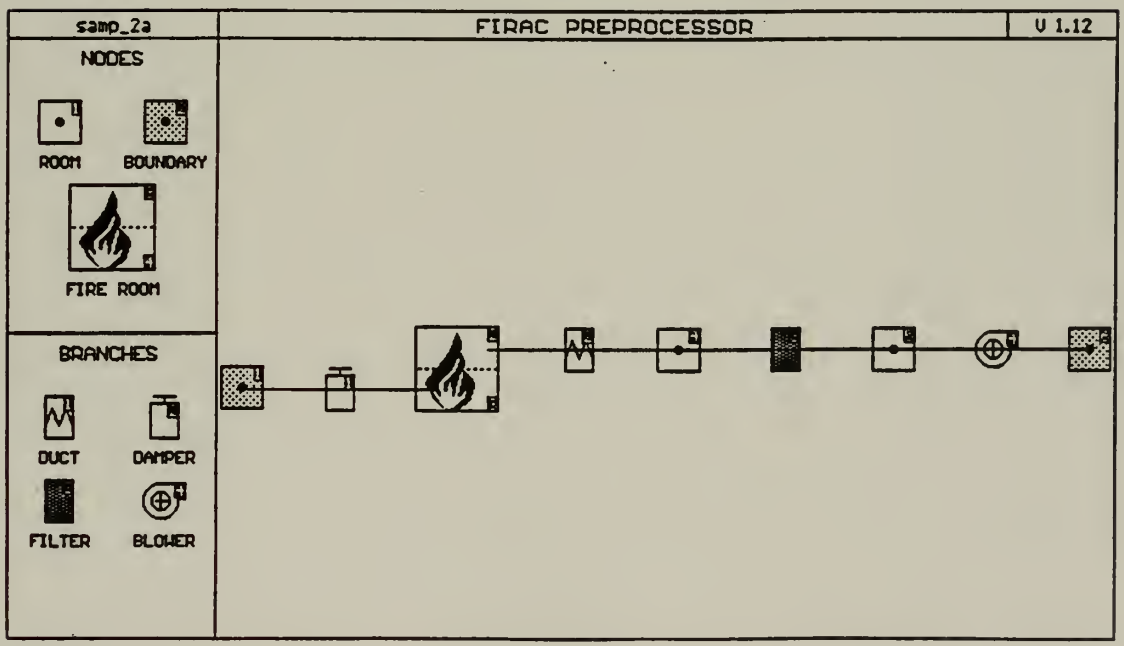


Figure 6.8: System network on the FIRAC pre-processor

RESULTS

Temperature

The output predictions are compared with the results calculated in the previous simulation. The change in room temperature from 60°F to 400°F is instantaneous since the kerosene was ignited at time zero. This rapid growth phase is short lived since it is a flash of flame. Comparing Figures 6.3 & 6.9, however, the effect of the 750 CFM blower is observed as decreasing the sustainment of the higher temperatures in the room. The decreasing slope is greater with the blower. The blower is evacuating the hot gases which helps to cool the room. The temperature difference of 25°F less is at the 175 second mark, while beyond this point both temperatures in the simulations decrease at the same rate.

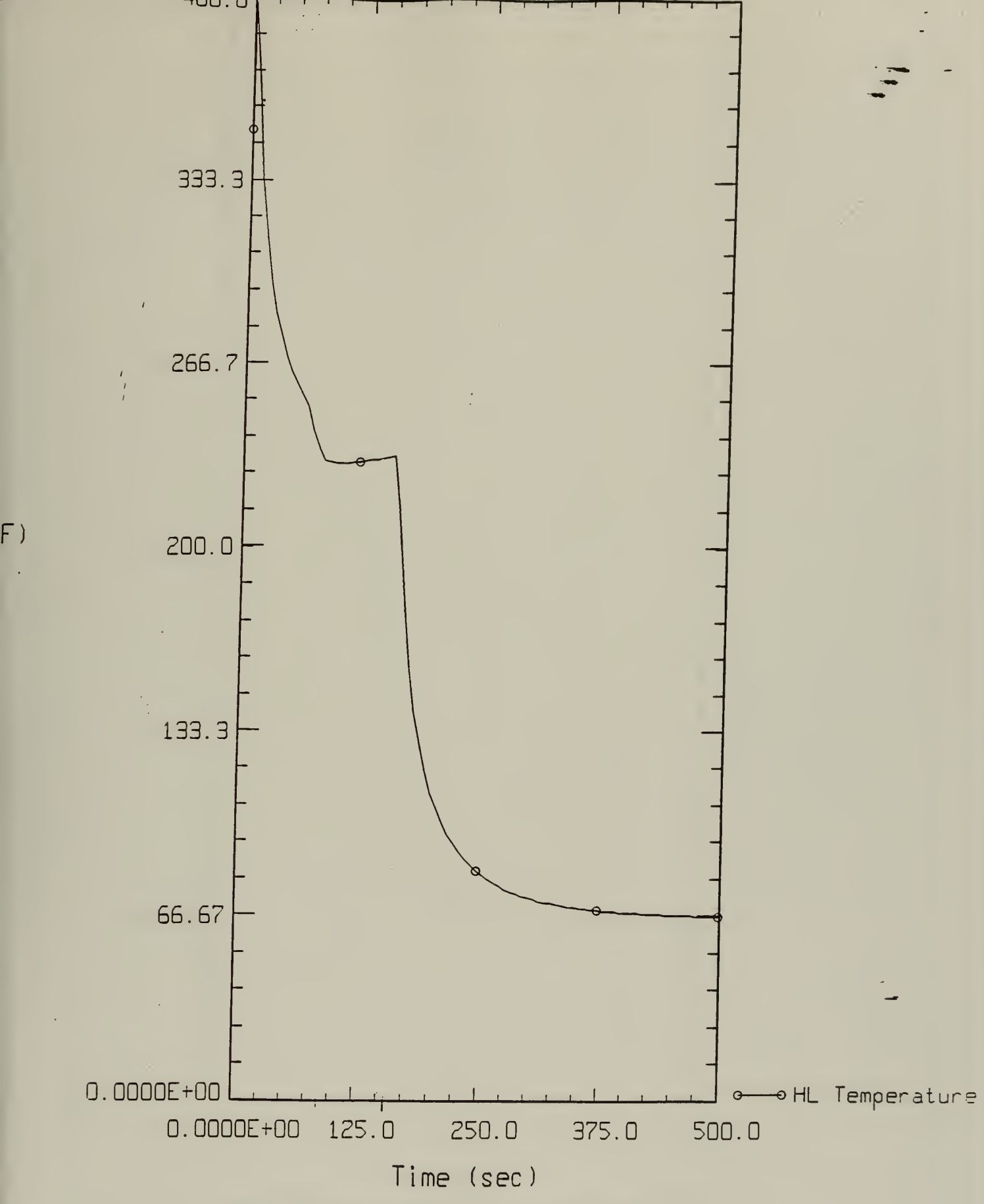


Figure 6.3: Hot layer temperature without a blower

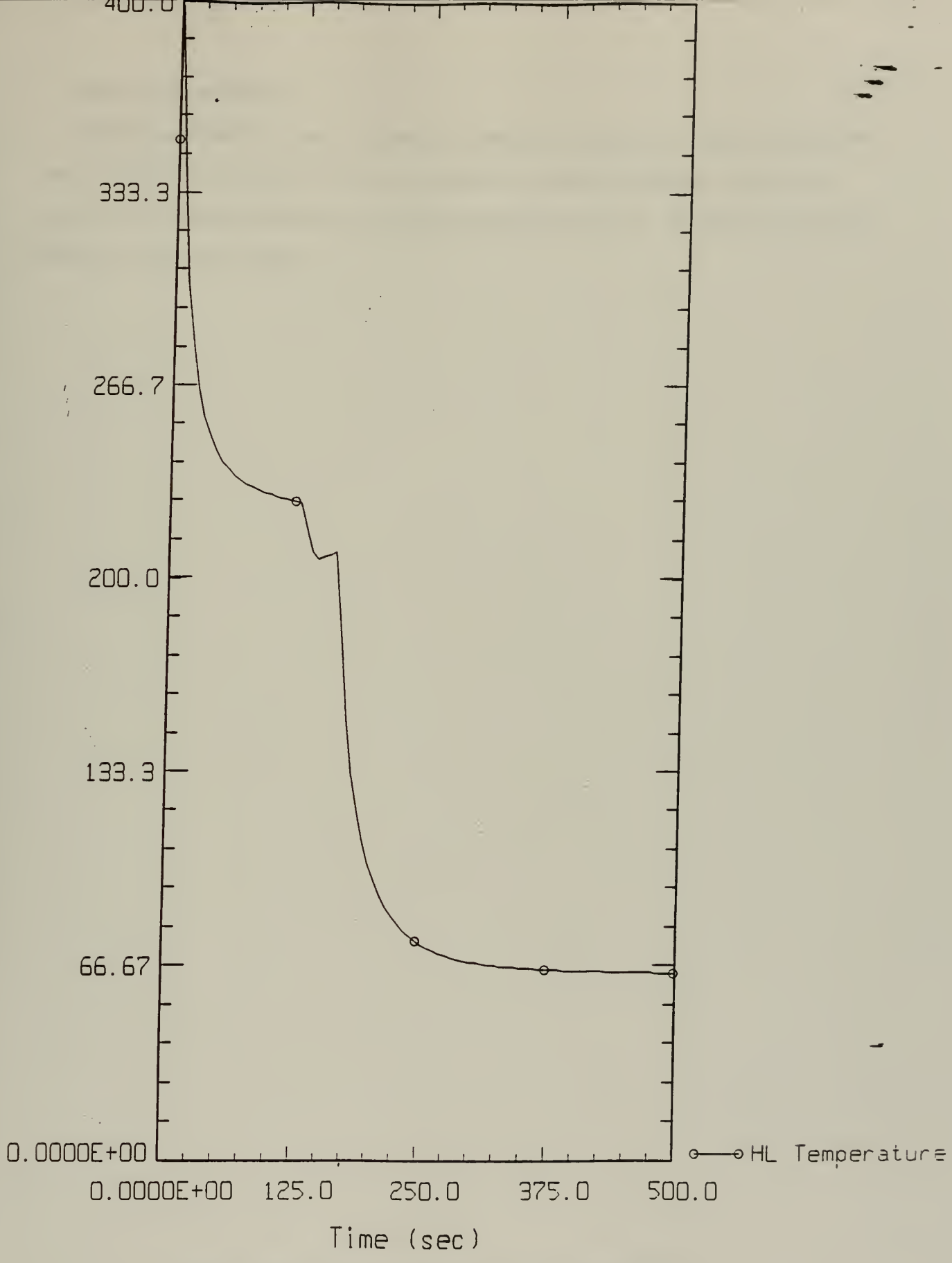


Figure 6.9 Hot layer temperature with 750 CFM blower

Smoke accumulation

Comparing Figures 6.4 and 6.10 there is a noticeable decrease in smoke accumulation rate with the 750 CFM blower. The blower helps to evacuate the smoke. At the 500 second mark without the blower, the smoke accumulation value is .167 grams while with a blower the value is 15 grams.

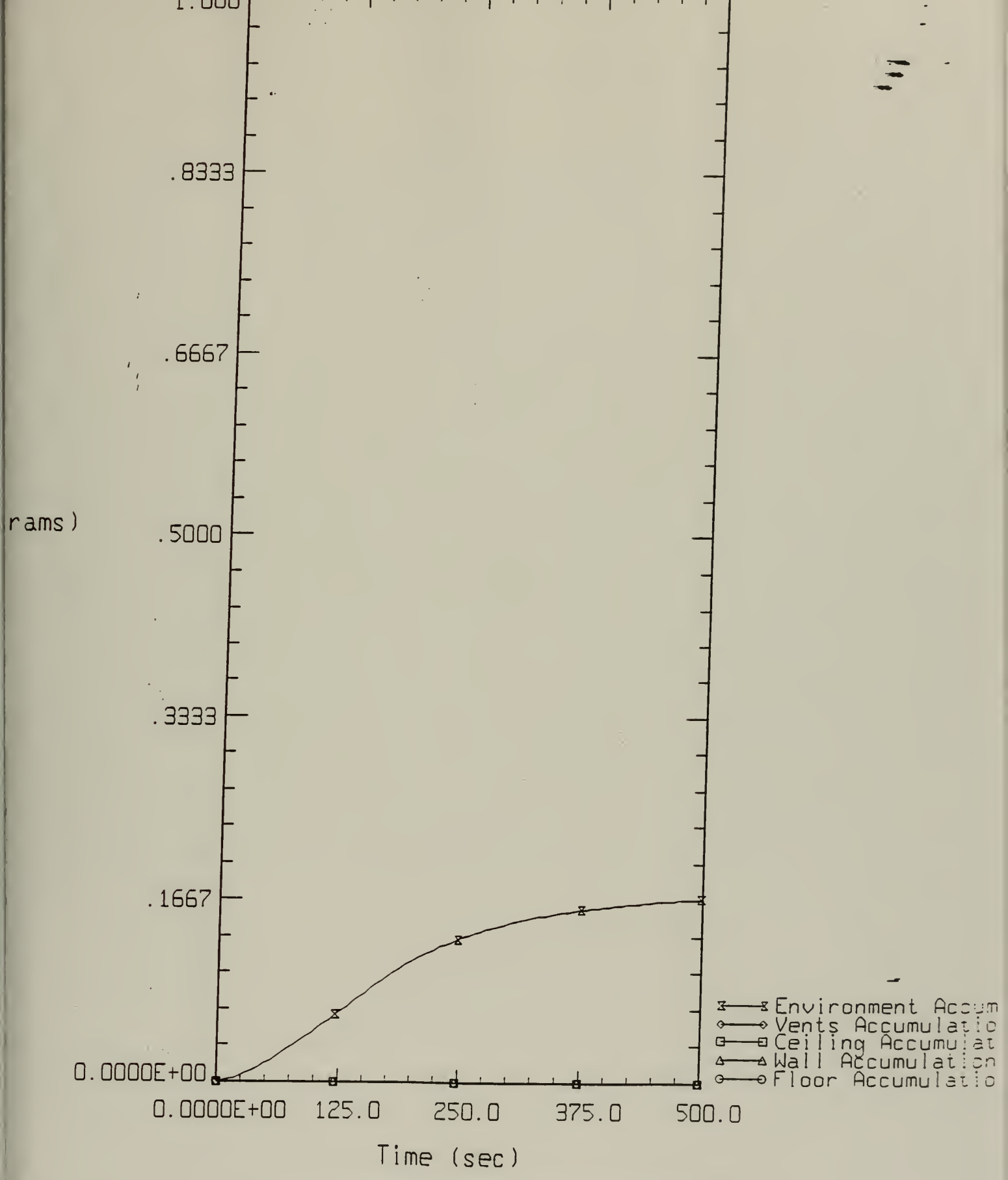


Figure 6.4: Smoke accumulation without a blower

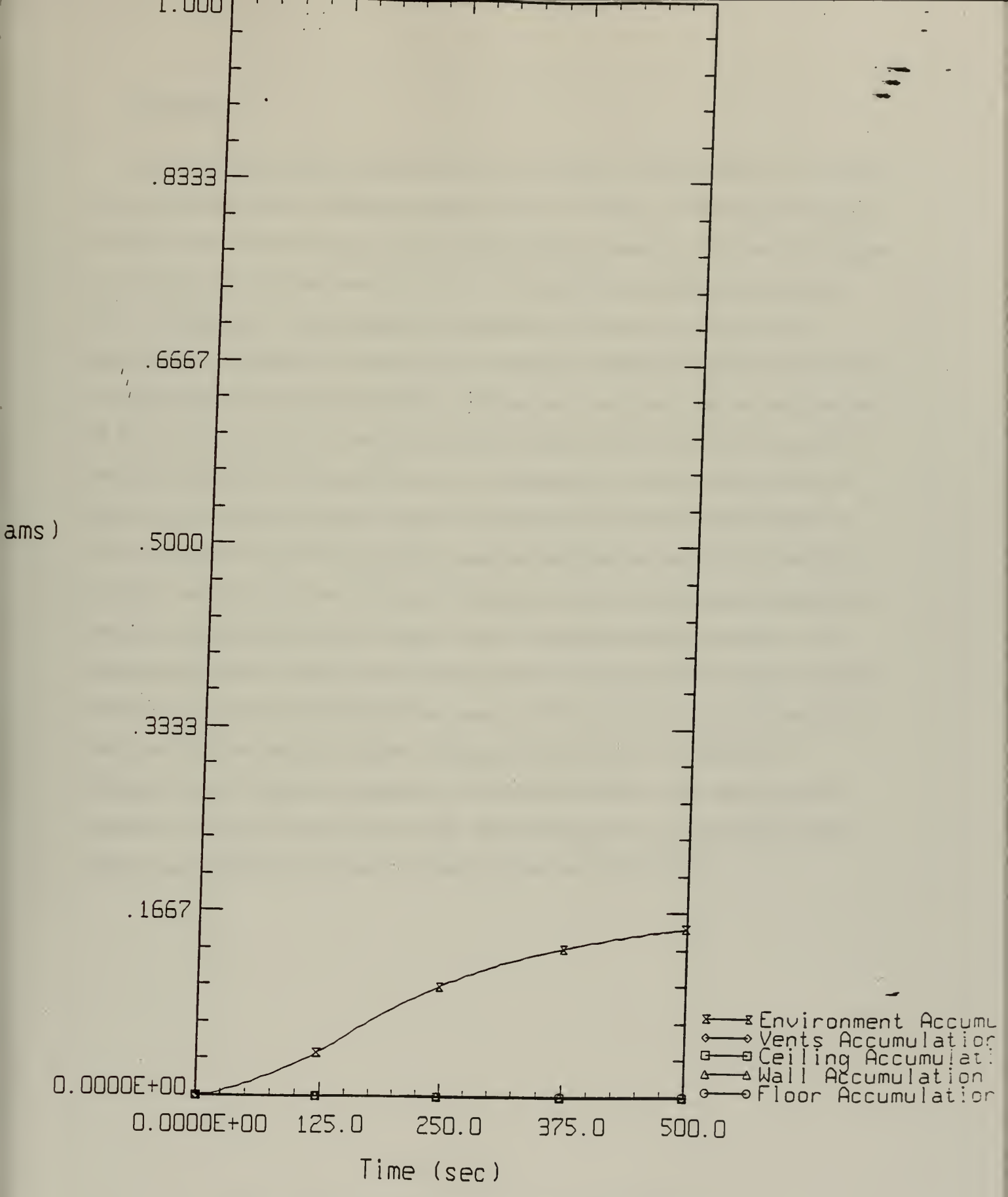


Figure 6.10 Smoke accumulation with a 750 CFM blower

Mass flows

Figure 6.11 shows the branch mass flows for the system. Within branch #1, the output shows the damper flow remaining constant at about 0.43 lb/hr. Realistically, the eruption of flame in the fire room would cause a sudden change in pressure which would propagate to the inlet portion of the ventilation system. This would have an effect on the damper flow. Beyond the fire room within the outlet section (branches 2, 3 & 4), the flow approaches 1.33 lb/hr at 25 seconds into the simulation. Before this point in time, the fuel undergoes a flash of flame upon ignition. This reaction would result in a dramatic increase in flow with the products of combustion quickly filling the fire room. Over the next 150 seconds the mass flow decreases by steps to a minimum of 0.53 lb/hr. This could be the result of the combustion products being evacuated by the decrease in pressure from the blower. Beyond the minimum mass flow value the flow then increases until approaching 1.00 lb/hr near the end of the simulation. Referring to a mass balance during that period, it would be expected that the flow would continue to decrease rather than increase. The combustion products would be evacuated with fresh air coming in from the inlet. In time, the flow would approach the steady state value of 0.43lb/hr which is the flow through the inlet portion of the ventilation system. Although the results are not included, the simulation was run again and extended to a 1000 second duration. The mass flow rate remained at 1.00 lb/hr beyond 500 seconds. This increasing trend of approaching a value greater than the inlet value is due to limitations of the code's algorithms.

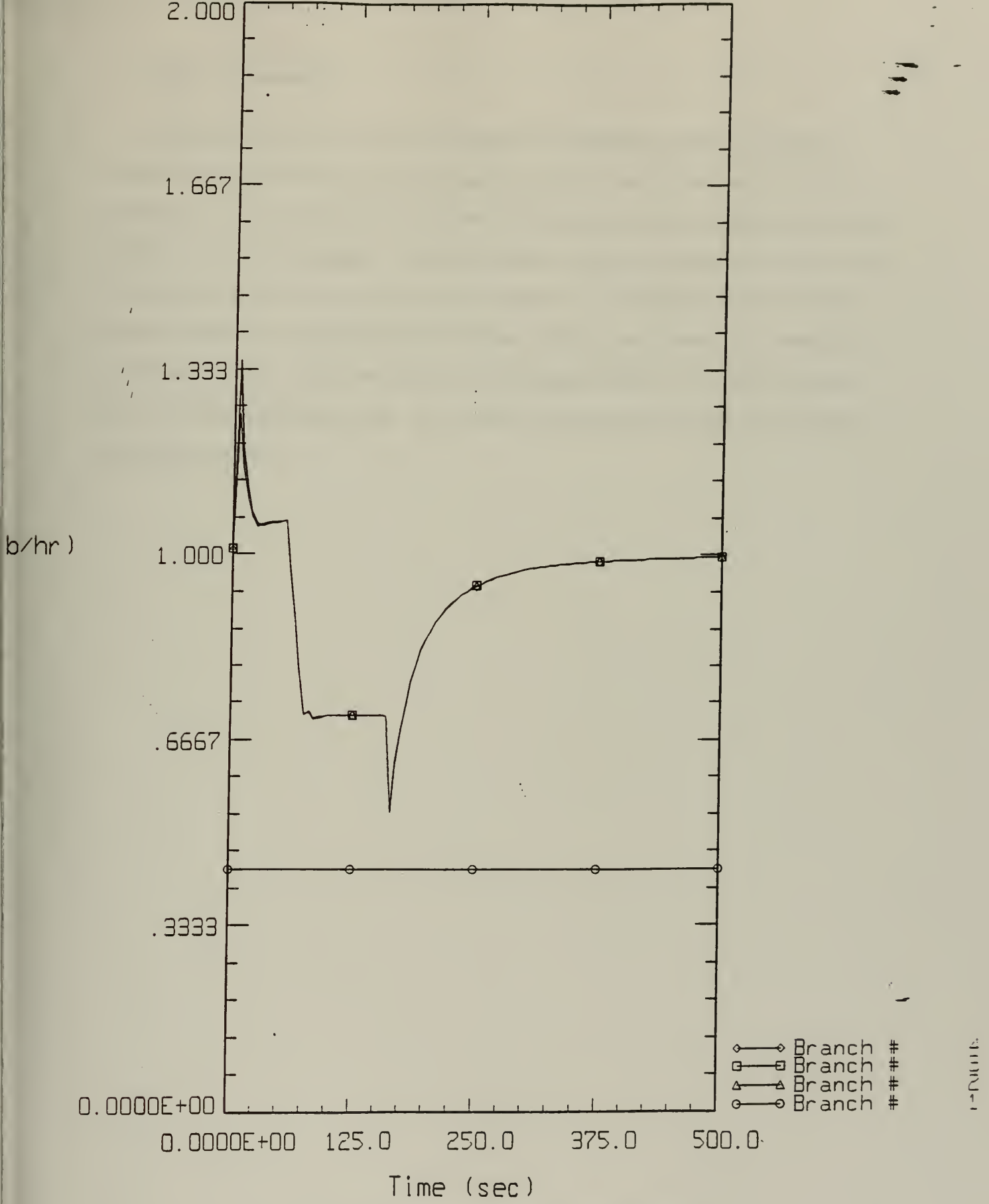


Figure 6.11: Mass flow 750 CFM blower

Nodal temperatures

Looking at Figure 6.12, the fire room (node #3) increases in temperature almost instantaneously while the nodes downstream of the fire room do not begin to increase until almost 75 seconds into the simulation. This demonstrates the sudden release in heat energy when the fuel is ignited. Over time the heat energy propagates through the outlet duct, as shown by the rise in temperature in nodes 4 & 5. There is a trade off in heat energy between the compartment and the nodes downstream. Beyond 175 seconds the nodes begin to cool. The blower evacuates the hot gases which are replaced with 60°F fresh air coming through the inlet. As a result, all nodes then approach the initial room temperature of 60°F.

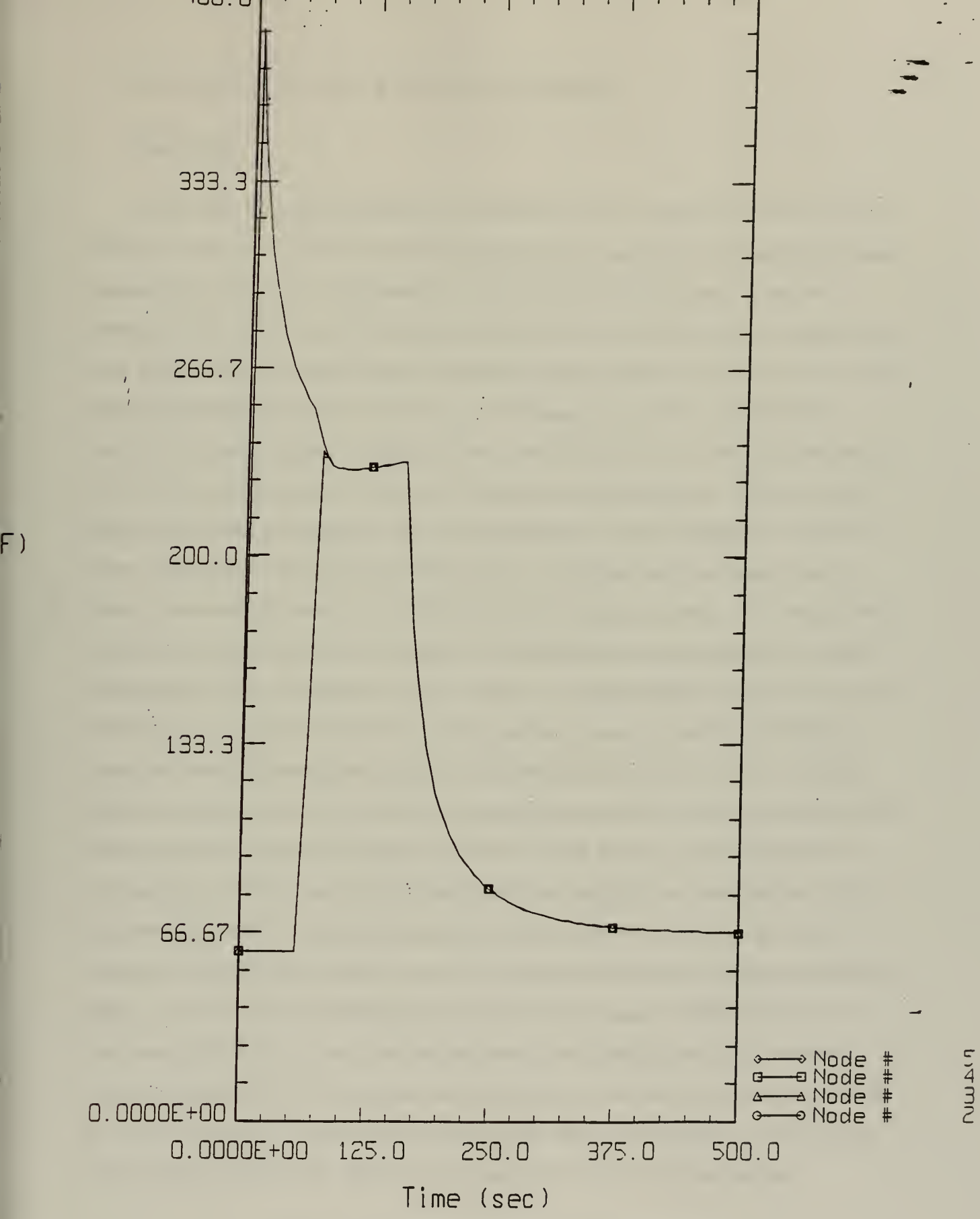


Figure 6.12: Nodal temperatures 750 CFM blower

COMPARISON 500 CFM & 750 CFM BLOWERS

Mass flows

To illustrate further system effects the simulation was run again but with a 500 CFM blower. Figures 6.11 & 6.13 are the branch mass flows. Looking at both graphs the same general trend is indicated. The mass flow rate in branch #1 the damper, is less with a constant value of 0.28 lb/hr. This is expected since the 750 CFM blower has a greater flow rate. Realistically, the damper flow would fluctuate rather than remain constant due to the sudden change in pressure in the fire room. The change in pressure is caused by the eruption of flame at ignition. Beyond the fire room within the outlet section (branches 2, 3 & 4), the flow approaches 1.23 lb/hr at 25 second into the simulation. This value is less than the maximum obtained from the 750 CFM blower. A lower maximum is due to the lesser volume flow rating of the 500 CFM blower. The flow tapers off quicker with a more pronounced minimum value of 0.29 lb/hr at the 150 second mark. This would imply that within the network there is a reverse flow since the value is less than the flow value through the intake. If reverse flow were to occur, it would probably happen at the time of fuel ignition. At ignition is when there is the greatest pressure disruption. The pressure disruption would be propagated through the system much like a shock wave. The duct sections are short, less than 15 feet, so the pressure wave would be felt in the exhaust duct section instantly. Beyond the minimum mass flow value, the flow then increases until approaching 7.33 lb/hr near the end of the simulation. Referring to a mass balance during that period it would be expected that the flow would continue to decrease rather than increase. The combustion products would be evacuated with fresh air coming in from the intake. In time the flow would approach the steady state value of .28lb/hr which is the flow through the inlet portion of the ventilation system. Although the results are not included, the simulation was run again and extended to a 1000 second duration. The mass flow rate remained at .28 lb/hr beyond 500 seconds. This increasing trend of approaching a value greater than the inlet value is due to limitations of the code's algorithms.

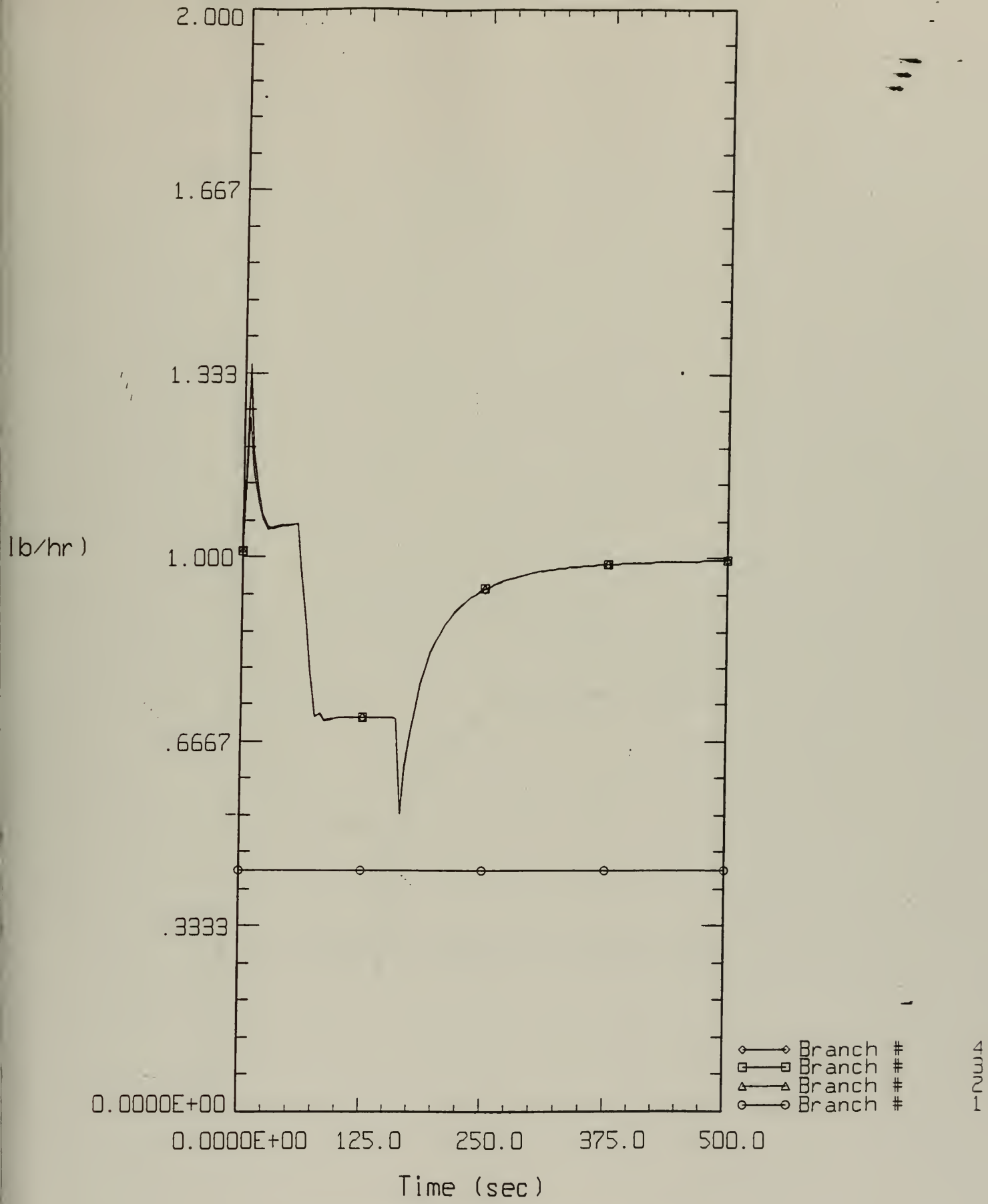


Figure 6.11: Mass flow 750 CFM blower

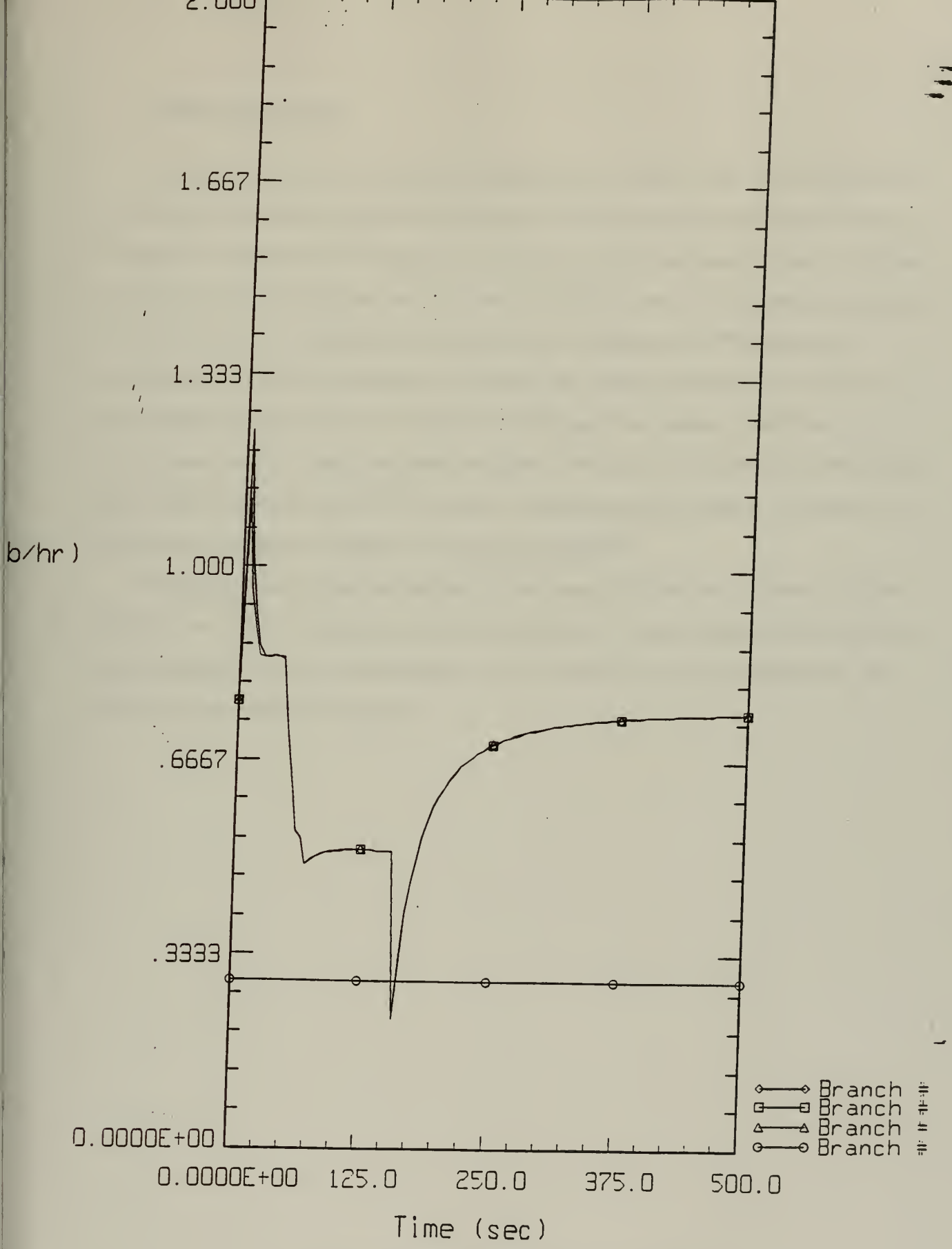


Figure 6.13: Mass flow 500 CFM blower

Nodal temperatures

Figures 6.12 & 6.14, are the nodal temperatures for both 750 & 500 CFM blowers. Both graphs are similar in trends with the trade off in heat energy demonstrated by the changes in temperatures. In Figure 6.14, node #3, the fire compartment reaches a greater maximum value than the fire room with the 750 CFM blower. This temperature is greater since hot gases are evacuated at a lower flow rate. With the 500 CFM blower the sustainment of a higher temperature is longer at the nodes downstream of the fire room due to the reduced flow rate. Hot gases travel through the system slower, thus duct components remain at high temperatures longer. Over time the blower evacuates the hot gases which are replaced with 60°F fresh air coming through the intake. As a result, all nodes then approach the initial room temperature of 60°F.

Although the results are not included in this report the CFM was increased to 2000 CFM to see what the limitations were for this problem. At this volumetric flow rate the code could only carry out the simulation to 250 seconds with no recorded results. At 2500 the code would not execute.

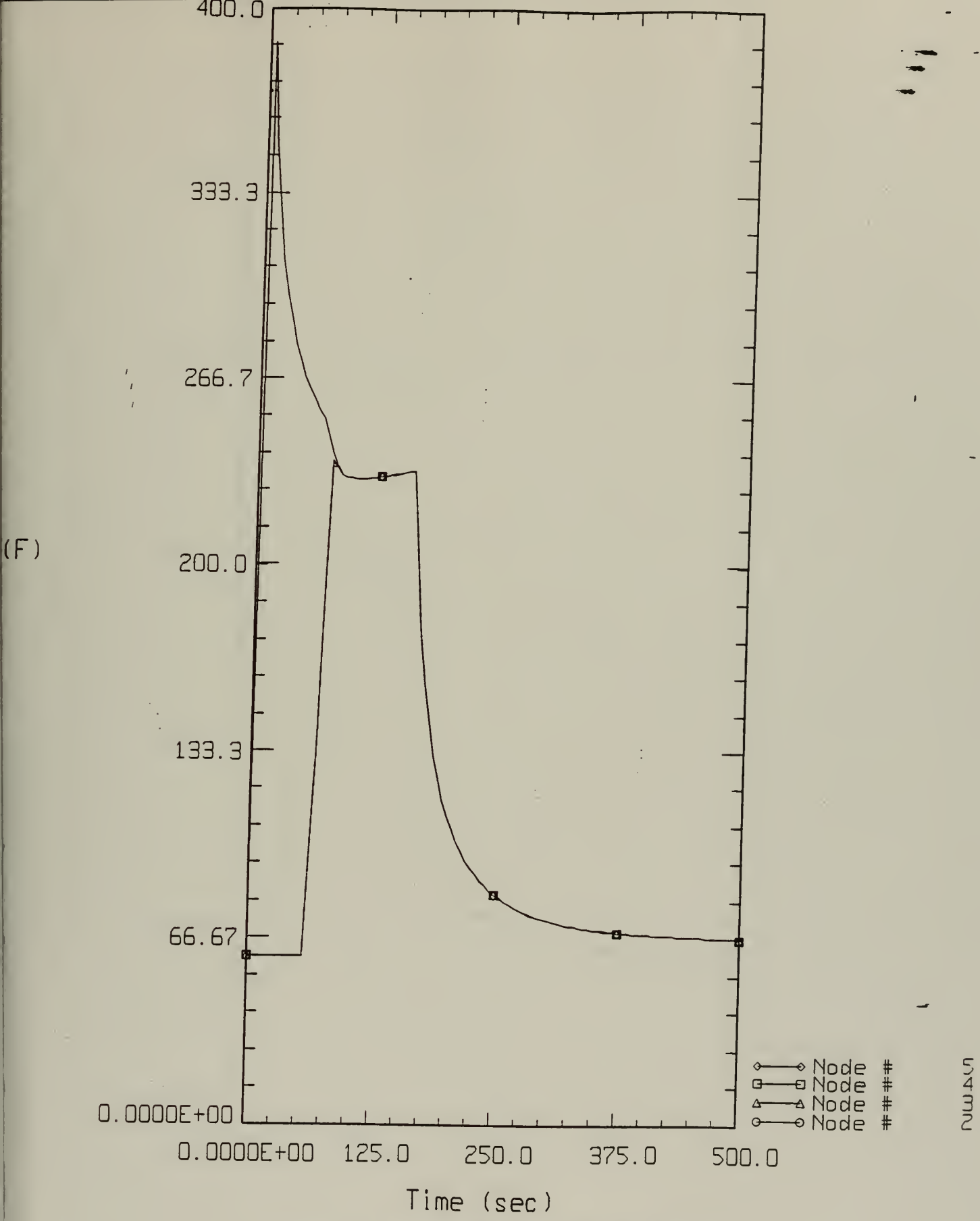


Figure 6.12: Nodal temperatures 750 CFM blower

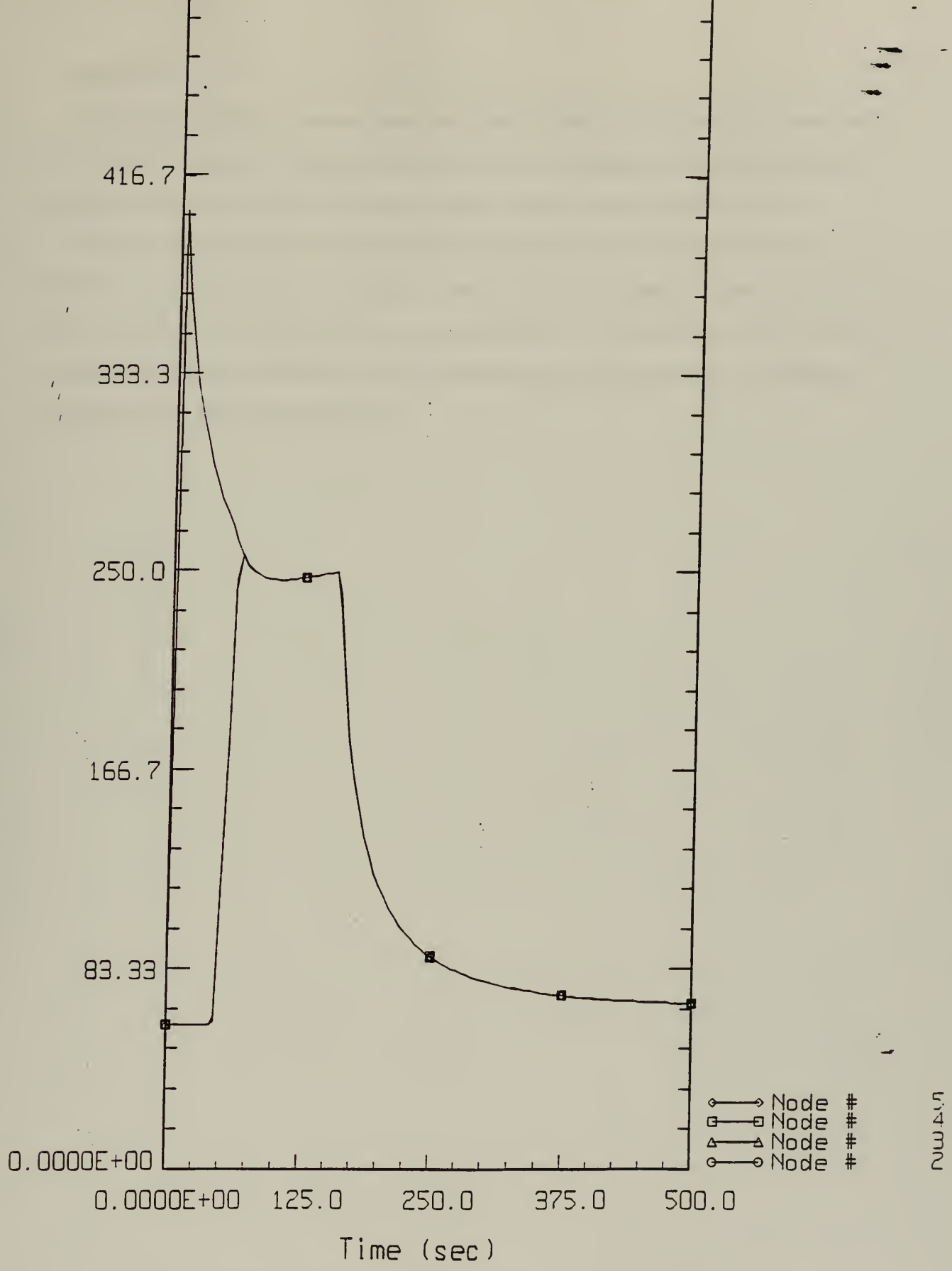


Figure 6.14: Nodal temperatures 500 CFM blower

Summary

The second simulation demonstrated the dynamic effects on the system for an isolated fire incident. Through an increase in flow not only was a change in temperature and flow magnitudes demonstrated but that change could be observed with respect to time.

The simulations chosen to be executed were simple to give the potential user an overview of the capabilities of the FIRAC code. The FIRAC code is a systems model since it can predict the effects of a fire on an entire facility. Those effects are the result of the thermal and pressure transients which upset the normal flow pathways in addition to spreading smoke throughout the facility.

RECOMMENDATIONS/IMPROVEMENTS

FIRAC is a powerful package with great potential that combines the advantages of a both systems and compartment models. It can predict the burning and specie release of radioactive material which no other software package is capable of at this time. It is menu driven which makes it easy to input data. It has an extensive material data base to model the fire compartment.

The present DOS version would be more user friendly if updated into the Windows environment. Being a derivative of a mainframe code it has the remnants of three physically separate processes that the user must manually perform. The three are:

- pre-processor (inputting data, building system components)
- FIRAC(executing data)
- post (graphical presentation files)

The user has to save and exit each of these executable files and run each one to completion to pass on to the next step. The three could be combined into the pre-processor as pop-up menus and be observed when running a scenario. Consequently, graphical results could be observed in real time and be stopped to make minor changes to system components and observe immediate effects. These changes could include modifying the fire compartment such as opening a door or the system such as closing a damper. The user could choose the nodes/branches to be observed during scenario execution.

The effect of modeling the burning and specie release of radioactive material could be enhanced and applied to the hazardous waste industry. A database including common hazardous wastes could be added to the fire compartment. The particles could be tracked through the system much like smoke particulates.

The choice to install fire suppression systems could be added to the fire compartment to predict their capability to minimize casualty losses.

A flow network is modeled from the building system using nodes and branches where the maximum problem size is restricted to 100 nodes. Each component such as a blower or damper within a representative facility takes two nodes and two branches to model.

Depending upon the number of duct increment measurement points, more nodes/branches would be required. The user has to keep this in mind when constructing a network and incorporating the desired detail. Although the requirement for accurate data may be paramount except certain assumptions and estimates may be used to make the scenario more controllable.

When running the dynamic simulations at times predictions did not agree with physical reasoning. As a result an in depth study is required to determine calculation procedures utilized. A true test would be to verify the results with small scale real fire scenarios.

FIRAC provides the engineer, architect, or scientist an excellent supplementary tool that can be applied in the design phase to test real scenarios for a facility catastrophe. With introduction of the PC version scenarios could be run at the designers desk to test what-if and formulate actions at a much lower cost then running actual destructive tests. Although the predictions are approximate they are presented with respect to time which in a fire seconds could mean the difference between life and death.

CHAPTER 7

CFAST SIMULATION OF BACKDRAFT

If there is inadequate ventilation available to a fire during the growth phase, then the fire may not flashover due to an inadequate supply of oxygen. The fire may die out completely, or continue to smolder. This smoldering is very dangerous because with a depleted oxygen supply unburned flammable vapors can begin to collect in the space. In an atmosphere of incomplete combustion, carbon monoxide gas which has an explosive range from 12.5° F to 74° F and an ignition temperature of 1,200° F is generated.[7] Carbon particles are also dispersed in the air (ignition temperature 400° F). Upon entry of oxygen the carbon particles can ignite the carbon monoxide gas and set off a rapid powerful explosion. The phenomenon is known as backdraft. This could happen with the opening of a door. This eruption of flame and/or explosion is so intense it can immediately kill the unsuspecting victim.

BACKDRAFT MODEL

This backdraft phenomenon will be modeled in this simulation. The model consists of a single room connected to a stairwell by a closed door. The room dimensions are 18' X 42' X 8'. The stairwell is modeled as a second room of dimensions 3'X 9'X 27'. The fire is a customized T-squared growth rate fire with a peak release of 1 MW. This growth rate is characteristic of most common items of residential contents. This peak was reached only for a short time due to the limited amount of oxygen in the room. About three quarters into the simulation the door was opened between the room and the stairwell. Figure 7.1 is a schematic of the room with stairwell.

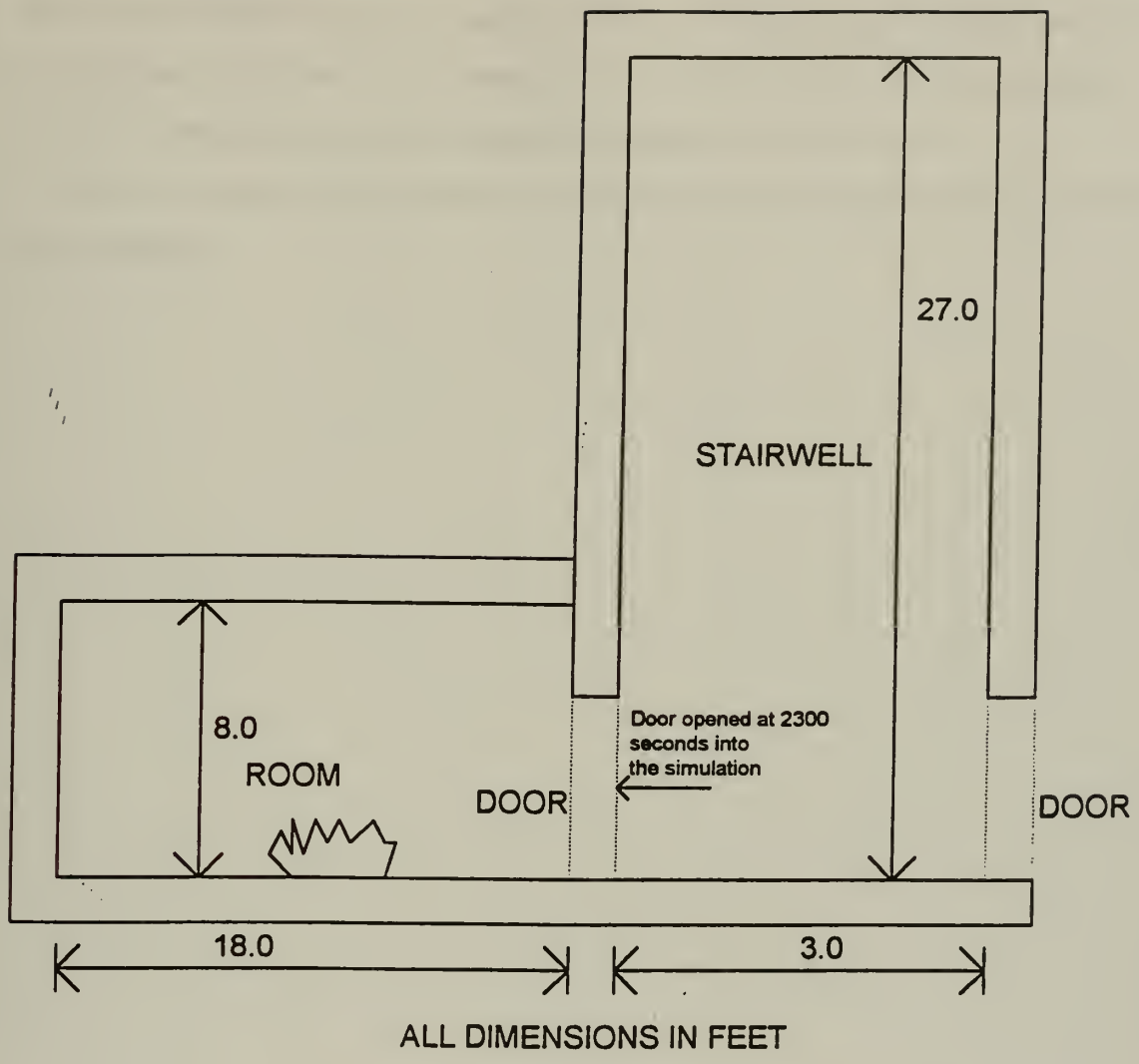


Figure 7.1: Schematic of room with stairwell

RESULTS

Figure 7.2 shows graphs of heat release rate, upper layer temperature, and interface height all which display the dynamic effects of a backdraft. Looking at the heat release rate the fire grew and peaked to about 1 MW around the 750 second mark. Then it began to decrease due to the amount of oxygen that was available in the room. Although not out, during this time the fire was smoldering. The room receiving fresh air from both a small vent and the space under the door allowed just enough oxygen for this to occur. Then the door to the stairwell was opened. Thus the dramatic increase in the heat release

rate which peaks at 5 MW, in the stairwell by the fueling of fresh air from an open door. The corresponding temperature reaches 1200K (1700°F), 5 times the peak rate in the fire compartment. As expected at the same time the hot layer height drops dramatically. Anyone in the stairwell would be engulfed in flames and not survive.

For the potential user appendix C contains the input and output data files for running this simulation.

Figure 7.2: Simulation results

SUMMARY

Fastlite provides a powerful user friendly package to predict effects of a fire. Its strong point is the real time updates and ability to make modifications without sacrificing a data run. The accuracy of the model is limited by the fire being uninfluenced by radiation from its surroundings. Although further research is on going to better understand radiation enhanced burning along with predicting fire growth under these conditions. In addition it is difficult to quantifying the psychological effects of fire on people and what their resulting actions would be.

REFERENCES

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6. Drysdale, D. (1985). *An Introduction to Fire Dynamics*, John Wiley and Sons, New York

7. Wescott, Joseph M. (March/April 1996). "More on Defining a Backdraft", National Fire Protection Association Journal, Quincy, MA

8. Stollard P. & Johnston L. (eds) (1994). *Design Against Fire*, Chapman & Hall, London, UK

Appendix A

This appendix will provide a step by step guide to inputting and running the problems discussed in the simulation portion of this paper

The FIRAC PC version runs in the DOS environment and consists of three executable files they are:

- FP - FIRAC pre-processor, building the network
- FIRAC - executes the calculations
- POST - stores data for presentation in graphical form

It is recommended to keep all these file in one directory entitled FIRAC since they are interdependent.

Change directories to enter the directory titled FIRAC.

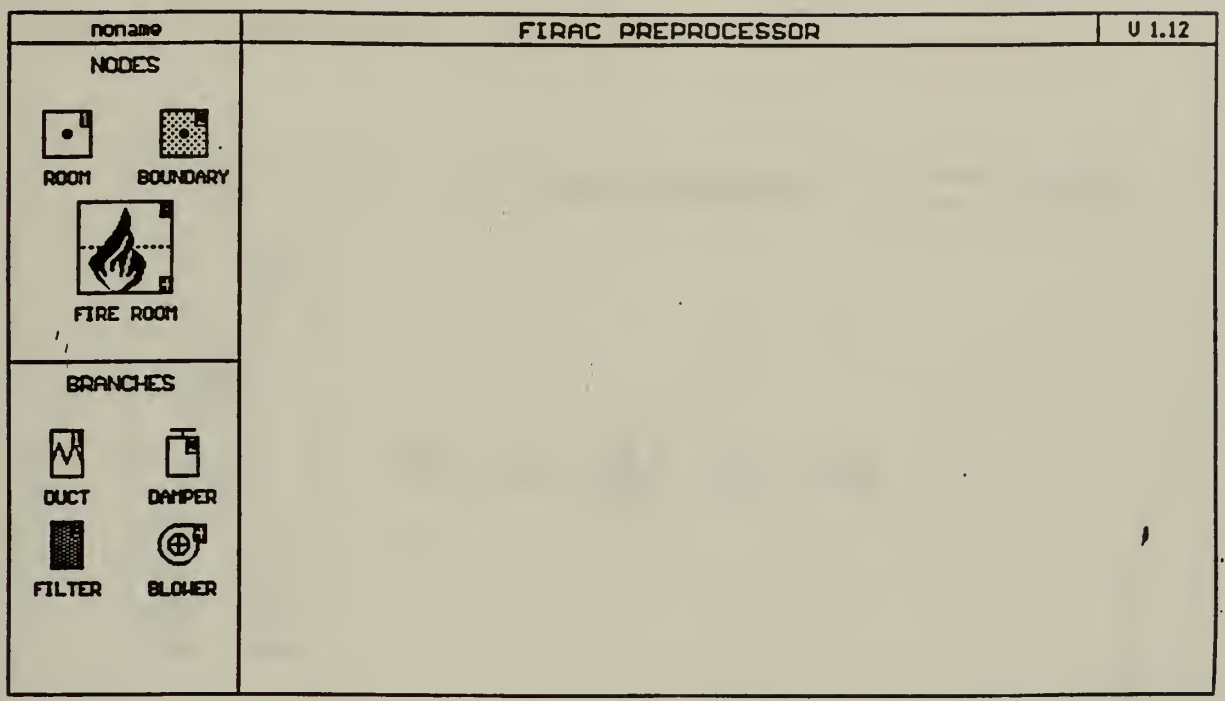
Running the pre-processor

Once in the FIRAC directory to activate the pre-processor type:

fp name of your model (fp samp_1a)

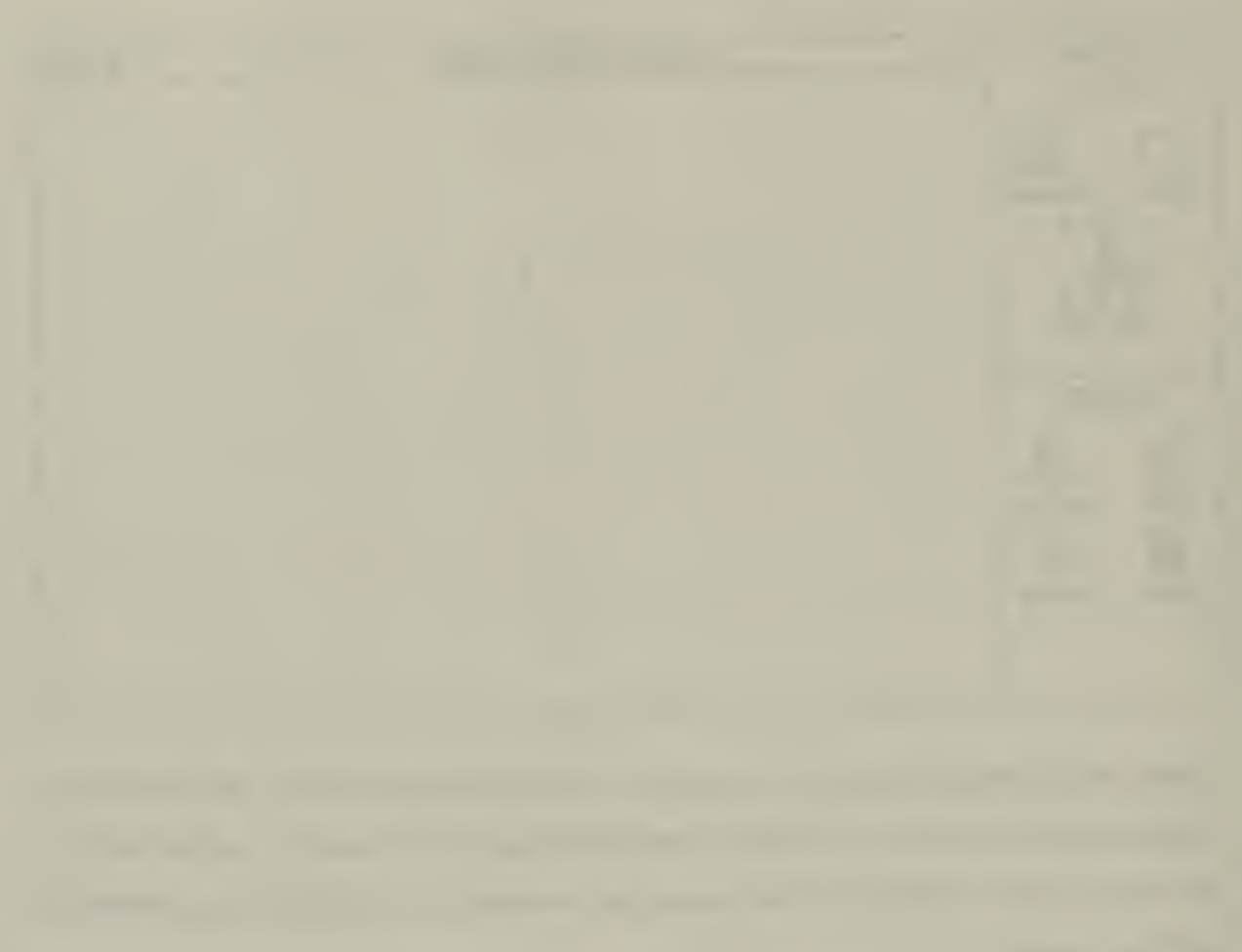
The name of your file can be any combination of alphanumeric characters as long as it is less than 7 characters long. The name must be chosen prior to inputs or else the program will use a default title noname.

The pre-processor screen will look like this:

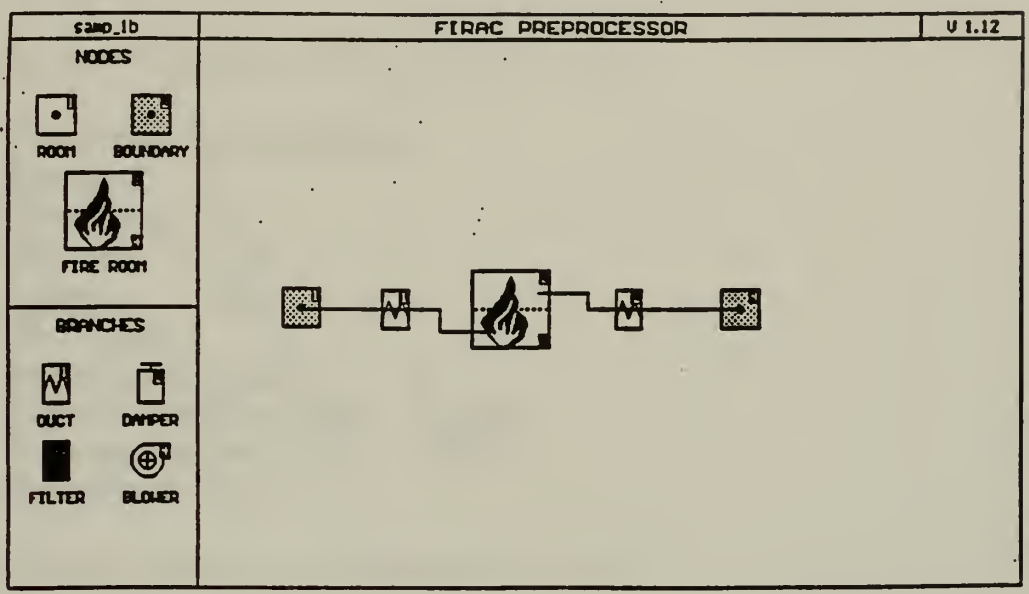


Notice that the name the user has chosen is in the upper left hand corner. On the left side of the screen are the node and branch components that can be chosen by a mouse to build the network. In the lower part of the screen are the choices for inputting the parameters to build the network.

The quickest way of constructing a network is to first choose and connect the components then fill in all data later.



Choose all components using the mouse then double click to place them on the screen. The network we are building consists of two boundary nodes two duct branches and one fire room. It should look like:

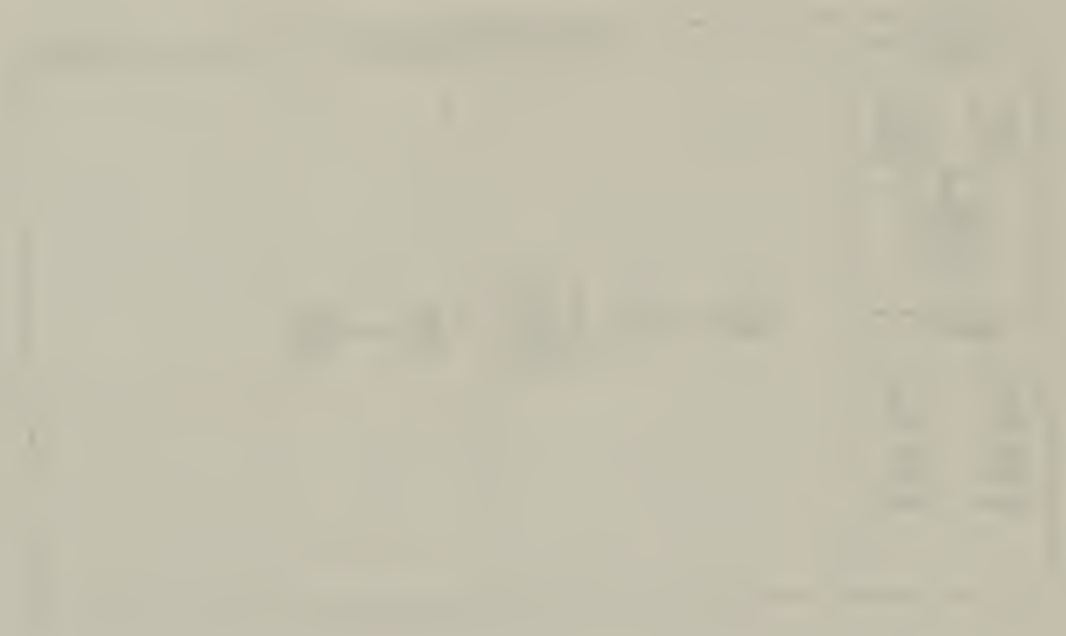


Now the parameters can be input for each component

Select the modify section in the lower portion of the screen.

Select the boundary node #1 and fill in the following information:

Description: Type in Inlet boundary
Elevation: 0.0
Pressure: 0.0
Temperature: 60



Select the boundary node #2 and fill in the following information:

Description: Type in Exhaust boundary
Elevation: 0.0
Pressure: -1.0
Temperature: 60

Select the duct #1 and fill in the following information:

Description: Type in Inlet duct
Upstream: 1
Downstream: 3
Flow area: 3.14
Length: 0.0
Flow 750
Pressure differential(DP): 0
K (forward resistance coef): 1.60534
K (reverse resistance coef): 1.60534
Heat transfer option: 0

Select the duct #2 and fill in the following information:

Description: Type in Exhaust duct
Upstream: 2
Downstream: 4
Flow area: 3.14
Length: 0.0
Flow 750
Pressure differential(DP): 0
K (forward resistance coef): 1.60534
K (reverse resistance coef): 1.60534
Heat transfer option: 0

Select the Run control option and fill in the following information:

Run option: ST
Start time: 0.0
End time: 500
Output increment: 0.1

Select Time domains and fill in the following information:

Domain#1
- Time step: .01
- End time: 1.0
- Print interval: 1.0

Domain#2
- Time step: .01
- End time: 500.0
- Print interval: 1.0

Select Fire room and the FIRIN module window will display.

Select Run control and fill in the following information:

Fire duration: 1000.0
Fire start time: 0.0
Print interval: 20

Select Fire source and choose burning option and fill in the following information:

Burning order option: 1

Kerosene
- Mass: 2.0
- Surface area: 5.0

Select Compartment and fill in the following information:

Compartment
- Pressure: -0.55
- Temperature: 60.0
- Length: 16.0
- Width: 12.5
- Height: 12.0
- Flame base elevation: 0.0

Ceiling
- Thickness: 1.0
- Temperature: 60.0
- Material: 1 (concrete)

Walls
- Thickness: 1.0
- Temperature: 60.0
- Material: 1 (concrete)

Floor

Thickness: 1.0
Temperature: 60.0
Material: 1 (concrete

Ventilation system

Elevation

Inlet: 2.0
Outlet: 10.5

Number of additional paths: 0

Select FIRAC branch connections and fill in the following information:

Inlet vent

Branch number: 1
Diameter: 2.0

Outlet vent

Branch number: 1
Diameter: 2.0

The data should now be saved. Return to the FIRAC pre-processor main window by hitting escape. Choose the save processor data option. This will create two files titled samp_1a.fid and samp_1a.fpr.

The data must now be prepared for the FIRAC input deck. Choose the Write FIRAC input option. This will create a file titled samp_1a.inp.

Now choose Exit to exit the pre-processor

Running FIRAC

At the FIRAC prompt type FIRAC. You will now be asked for the input file name. Type samp_1a.inp. Hit enter. All FIRAC input decks have the file extension *.inp*.

You will now be asked for the output file name. Type samp_1a.out. Hit enter. All FIRAC output decks have the file extension *.out*.

FIRAC will now begin processing the data. A counter will be displayed showing the problem duration time and the time it is written to file named firac.dat. When the processing is complete the statement: programmed stop will appear.

At this time the user can view the output prediction plots through the post processor. At the FIRAC prompt type post

The screen will then show:

Which option do you like?
1) FIRIN fire compartment graphics review
2) FIRAC ventilating system graphics review
99) exit to DOS

The user can choose either one for review. Type 1 or 2

When 1 is entered the user is given several choices for review which are plotted as a function of time including

Fire compartment thermal effects
Smoke source term vs. time
Particulate size distribution

When 2 is entered the user is prompted for the number of nodes to be reviewed and which numbered nodes. Hit enter after each entry. The following options for plots with respect to time are then given:

FIRAC node summary
FIRAC branch summary
Node summary for 1 species
Branch summary for 1 species

All plots can be compared with those included in the simulation portion of this report. The FIRAC documentation which shows all input values can be found in appendix B

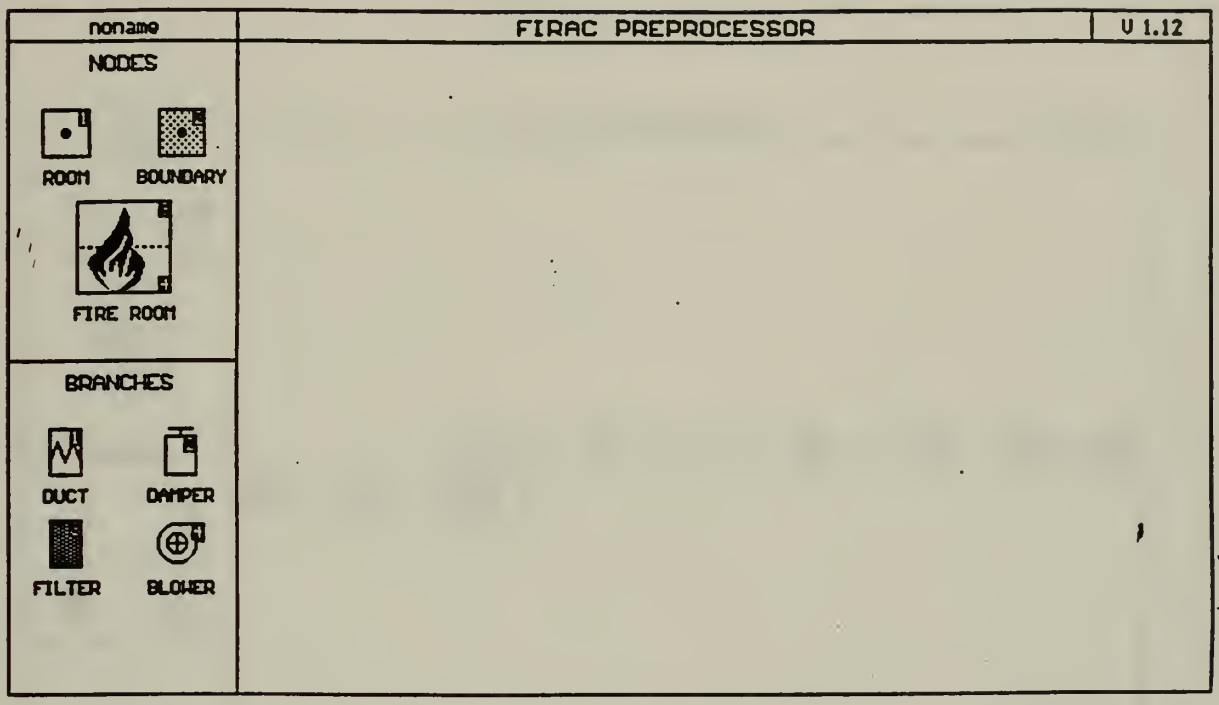
Simulation problem #2

Once in the FIRAC directory to activate the pre-processor type:

fp name of your model (fp samp_2a)

The name of your file can be any combination of alphanumeric characters as long as it is less than 7 characters long. The name must be chosen prior to inputs or else the program will use a default title noname.

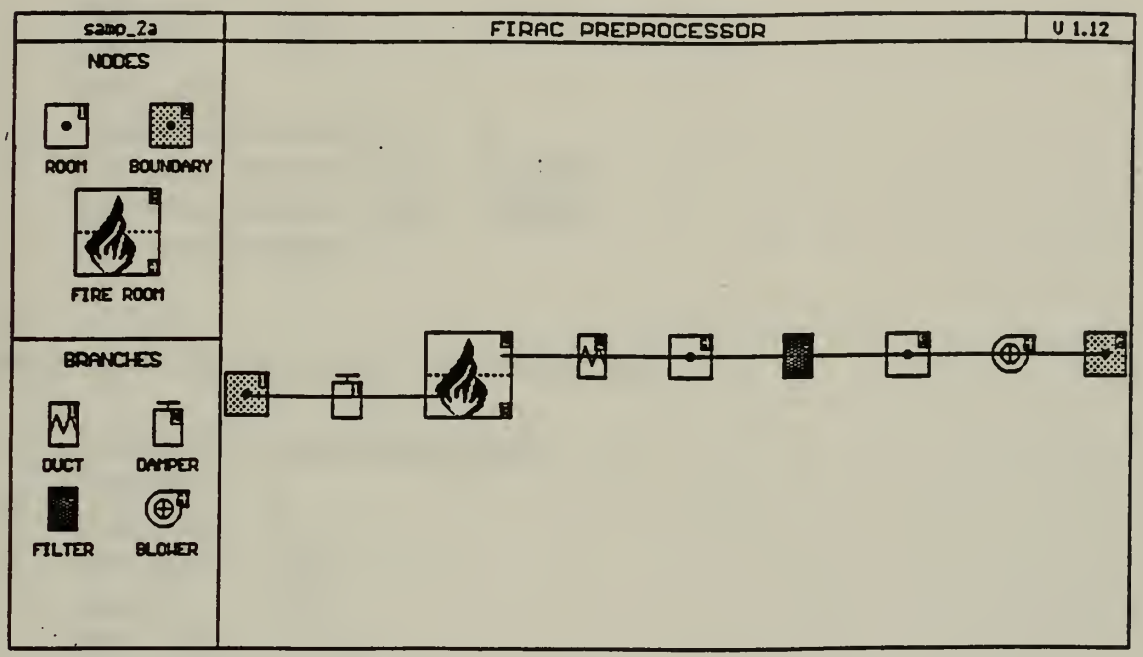
The pre-processor screen will look like this:



Notice that the name the user has chosen is in the upper left hand corner. On the left side of the screen are the node and branch components that can be chosen by a mouse to build the network. In the lower part of the screen are the choices for inputting the parameters to build the network.

The quickest way of constructing a network is to first choose and connect the components then fill in all data later.

Choose all components using the mouse then double click to place them on the screen. The network we are building consists of two boundary nodes, one damper, one duct, two room nodes, one filter, blower, and a fire room. It should look like:



Now the parameters can be input for each component

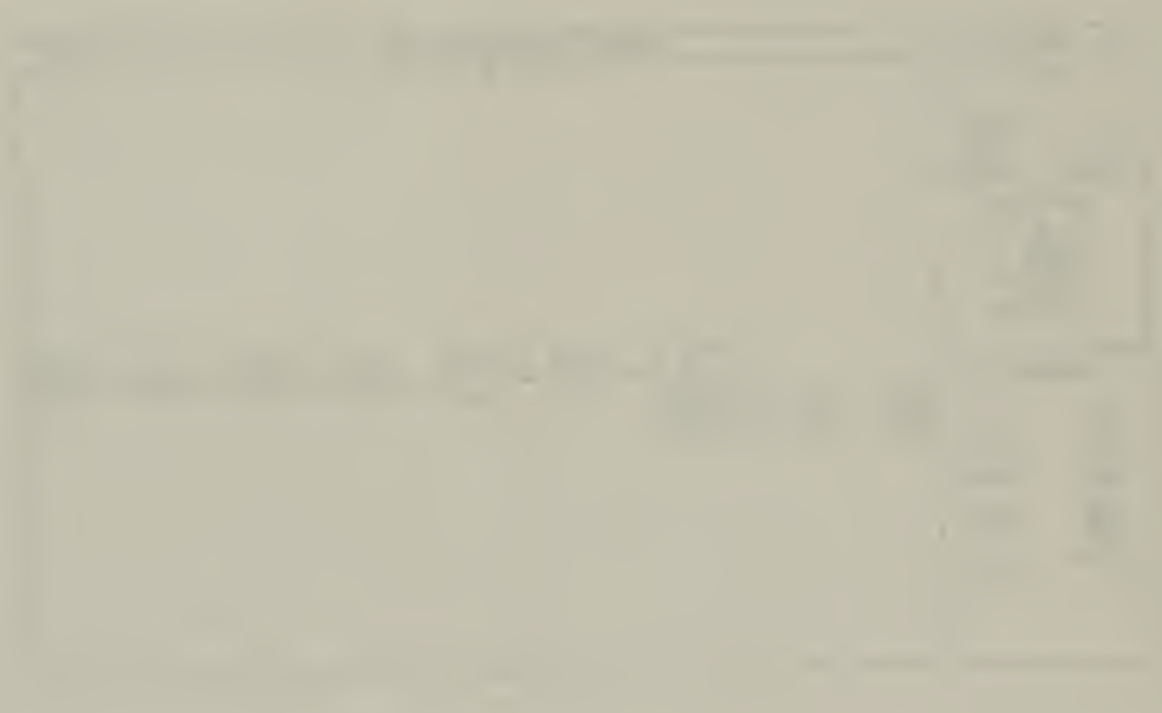
Select the modify section in the lower portion of the screen.

Select boundary node #1 and fill in the following information:

Description: Type in Inlet boundary
Elevation: 0.0
Pressure: 0.0
Temperature: 60

Select boundary node #6 and fill in the following information:

Description: Type in Exhaust boundary
Elevation: 0.0



Pressure: -1.0
Temperature: 60

Select damper #1 and fill in the following information:

Description: Type in Inlet damper
Upstream: 1
Downstream: 3
Flow area: 3.14
Length: 10.0
Flow 750
Pressure differential(DP): 0
K (forward resistance coef): 1.60534
K (reverse resistance coef): 1.60534
Heat transfer option: 0

Select duct #2 and fill in the following information:

Description: Type in Exhaust duct
Upstream: 2
Downstream: 4
Flow area: 3.14
Length: 8.0
Flow 750
Pressure differential(DP): 0
K (forward resistance coef): 1.58421
K (reverse resistance coef): 1.58421
Heat transfer option: 0

Select room node #4 and fill in the following information:

Description:
Type in: Exhaust duct node
Volume: 3.14
Flow area: 3.14
Elevation: 0.0
Temperature: 60

Select room node #5 and fill in the following information:

Description:
Type in: Exhaust duct node
Volume: 3.14
Flow area: 3.14
Elevation: 0.0
Temperature: 60

Select filter #3 and fill in the following information

Description:
Type in: HEPA filter
Upstream: 4
Downstream: 5
Flow area: 3.14
Flow 750
Pressure differential(DP): 0.7
Filter type: 1
Efficiency: 0.9

Select blower #4 and fill in the following information:

Description:
Type in: Exhaust blower
Upstream: 5
Downstream: 6
Initial flow: 750.0
Blower curve number: 1
Blower curve

Flow	Head
-8000	8.0
0.0	1.8
1200	1.528
6000	0.0

Select the Run control option and fill in the following information:

Run option: ST
Start time: 0.0
End time: 500
Output increment: 0.1

Select Time domains and fill in the following information:

Domain#1
Time step: .01
End time: 1.0
Print interval: 1.0
Domain#2
Time step: .01
End time: 500.0
Print interval: 1.0

Select Fire room and the FIRIN module window will display.

Select Run control and fill in the following information:

Fire duration: 1000.0
Fire start time: 0.0
Print interval: 20

Select Fire source and choose burning option and fill in the following information:
Burning order option: 1
Kerosene
Mass: 2.0
Surface area: 5.0

Select Compartment and fill in the following information:

Compartment
Pressure: -0.55
Temperature: 60.0
Length: 16.0
Width: 12.5
Height: 12.0
Flame base elevation: 0.0

Ceiling
Thickness: 1.0
Temperature: 60.0
Material: 1 (concrete)

Walls
Thickness: 1.0
Temperature: 60.0
Material: 1 (concrete)

Floor
Thickness: 1.0
Temperature: 60.0
Material: 1 (concrete

Ventilation system
Elevation
Inlet: 2.0
Outlet: 10.5
Number of additional paths: 0

Select FIRAC branch connections and fill in the following information:

Inlet vent
Branch number: 1
Diameter: 2.0

Outlet vent
Branch number: 1
Diameter: 2.0

The data should now be saved. Return to the FIRAC pre-processor main window by hitting escape. Choose the save processor data option. This will create two files titled samp_2a.fid and samp_2a.fpr.

The data must now be prepared for the FIRAC input deck. Choose the Write FIRAC input option. This will create a file titled samp_2a.inp.

Now choose Exit to exit the pre-processor

Running FIRAC

At the FIRAC prompt type FIRAC. You will now be asked for the input file name. Type samp_2a.inp. Hit enter. All FIRAC input decks have the file extension *.inp*.

You will now be asked for the output file name. Type samp_2a.out. Hit enter. All FIRAC output decks have the file extension *.out*.

FIRAC will now begin processing the data. A counter will be displayed showing the problem duration time and the time it is written to file named firac.dat. When the processing is complete the statement: programmed stop will appear.

At this time the user can view the output prediction plots through the post processor. At the FIRAC prompt type post

The screen will then show:

Which option do you like?
1) FIRIN fire compartment graphics review
2) FIRAC ventilating system graphics review
99) exit to DOS

The user can choose either one for review. Type 1 or 2

When 1 is entered the user is given several choices for review which are plotted as a function of time including

Fire compartment thermal effects
Smoke source term vs. time
Particulate size distribution

When 2 is entered the user is prompted for the number of nodes to be reviewed and which numbered nodes. Hit enter after each entry. The following options for plots with respect to time are then given:

FIRAC node summary
FIRAC branch summary
Node summary for 1 species
Branch summary for 1 species

All plots can be compared with those included in the simulation portion of this report. The FIRAC documentation which shows all input values can be found in appendix B

Appendix B

FIRAC documentation files

FP VERSION 1.12

FILE: samp_1b.doc

/* ********** RUN CONTROL DATA ********** */

Run Control Option: ST
Initial Output Time (s): 0.0
Time between Outputs (s): 0.1
Last Output Time (s): 500.0
No. Special Output Times (s): 0
  First:
  Second:
  Third:
  Fourth:
  Fifth:
Max. Iterations:
Convergence Criterion:
Particle Deposition:
Particle Entrainment:
Initial Pressure Input:
Initial Temperature Input:
Buoyancy Term:

/* ********** AMBIENT CONDITIONS ********** */

Pressure (psia): 14.696
Temperature (F): 60.0

/* ********** BOUNDARY NODES ********** */

Number of Boundary Nodes: 4

Description: INLET BOUNDARY
  Node Number: 1
  Node Type: 0
  Initial Pressure (in w.g.): 0.0
  Pressure Function I.D.:
  Initial Temperature (F): 60.0
  Temperature Function I.D.:
  Elevation (ft): 0.0

Description: FIRE INLET
  Node Number: 2
  Node Type: 1
  Initial Pressure (in w.g.): -0.5500116
  Pressure Function I.D.: 0
  Initial Temperature (F): 60.0
  Temperature Function I.D.: 0
  Elevation (ft): 0.0

```
Description:  FIRE OUTLET
  Node Number:  3
  Node Type:  1
  Initial Pressure (in w.g.):  -0.5500116
  Pressure Function I.D.:  0
  Initial Temperature (F):  60.0
  Temperature Function I.D.:  0
  Elevation (ft):  0.0

Description:  EXHAUST BOUNDARY
  Node Number:  4
  Node Type:  0
  Initial Pressure (in w.g.):  -1.0
  Pressure Function I.D.:
  Initial Temperature (F):  60.0
  Temperature Function I.D.:
  Elevation (ft):  0.0

/* ********** ROOMS ********** */

Number of Rooms:  0

/* ********** BRANCHES AND DAMPERS ********** */

Number of Branches:  2
Number of Control Dampers:  0

Description:  INLET DUCT
  Branch Number:  1
  Upstream Node Number:  1
  Downstream Node Number:  3
  Initial Flow (cfm):  750.0
  Flow Area (ft2):  3.14
  Duct Length (ft):  10.0
  Component Type:  D
  Pressure Differential (in w.g.):  0.0
  Blower Curve I.D.:
  Forward Resistance Coefficient:  1.60534
  Reverse Resistance Coefficient:  1.60534
  Filter Type:
  Duct Height (ft):
  Floor Area (ft):
  Heat Transfer Option:  0
  Roughness Height (m):
  Bend Angle (rad):
  Bend Radius (m):
  Drag Coefficient Factor:
  Shape Indicator:

Description:  EXHAUST DUCT
  Branch Number:  2
```

Upstream Node Number: 2
Downstream Node Number: 4
Initial Flow (cfm): 750.0
Flow Area (ft2): 3.14
Duct Length (ft): 10.0
Component Type: D
Pressure Differential (in w.g.): 0.0
Blower Curve I.D.:
Forward Resistance Coefficient: 1.60534
Reverse Resistance Coefficient: 1.60534
Filter Type:
Duct Height (ft):
Floor Area (ft):
Heat Transfer Option: 0
Roughness Height (m):
Bend Angle (rad):
Bend Radius (m):
Drag Coefficient Factor:
Shape Indicator:

/* ********** FILTERS ********** */

Number of Filter Types: 0

/* ********** PARTICULATE SPECIES ********** */

Number of Particulate Species: 0

/* ********** GAS SPECIES ********** */

Number of Gas Species: 0

/* ********** BLOWER CURVES ********** */

Number of Blower Curves: 0

/* ********** PRESSURE FUNCTIONS ********** */

Number of Pressure Functions: 0

/* ********** TEMPERATURE FUNCTIONS ********** */

Number of Temperature Functions: 0

/* ********** ENERGY FUNCTIONS ********** */

Number of Energy Functions: 0

/* ********** MASS FUNCTIONS ********** */

Number of Mass Functions: 0

```
/* ********** PARTICULATE SPECIES FUNCTIONS ********** */

Number of Particulate Species Functions:  0

/* ********** GAS SPECIES FUNCTIONS ********** */

Number of Gas Species Functions:  0

/* ********** TIME DOMAINS ********** */

Time Domain:  1
  Dtmax (s):  0.01
  Tend (s):  1.0
  Edint (s):  1.0

Time Domain:  2
  Dtmax (s):  0.1
  Tend (s):  500.0
  Edint (s):  1.0

/* ********************************** */
/* ********** FIRIN MODULE ********** */
/* ********************************** */

IFIRIN flag:  0

Inlet Node Number:  2
Outlet Node Number:  3
Third Node Number  0
Inlet Branch Number:  1
Inlet Branch Diameter (ft):  2.0
Outlet Branch Number:  2
Outlet Branch Diameter (ft):  2.0
Third Branch Number:
Third Branch Diameter (ft):
Third Branch Elevation (ft):
Third Branch Flow Direction:

/* ********** RUN CONTROL DATA ********** */

Fire Duration (s):  1000.0
Fire Start Time (s):  0.0
Print Interval (time steps):  20

/* ********** HEAT SINKS ********** */

Number of Heat Sinks:  0

/* ********** POWDER CONTAINERS ********** */
```

```
Number of Powder Containers:  0

/* ********** CLOSED LIQUID CONTAINERS ********** */

Number of Closed Liquid Containers:  0

/* ********** OPEN LIQUID CONTAINERS ********** */

Number of Open Liquid Containers:  0

/* ********** BURNING LIQUIDS ********** */

Number of Burning Liquids:  0

/* ********** BURNING SOLIDS ********** */

Number of Burning Solids:  0

/* ********** HEATED SURFACES ********** */

Number of Heated Surfaces:  0

/* ********** BURNING METALS ********** */

Number of Burning Metals:  0

/* ********** FIRE SOURCE DATA ********** */

Ignition Energy Flag:  1
  0=Burning Order
  1=Ignition Energy
  2=Burning Rate

Maximum Burning Order:  2

Burning Order:  1
Combustible 1 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 2 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 3 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 4 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 5 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 6 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 7 Fuel Mass (lbm):  2.0
              Surface Area (ft2):  5.0
Combustible 8 Fuel Mass (lbm):
```

```
              Surface Area (ft2):
Combustible 9 Fuel Mass (lbm):
              Surface Area (ft2):

Burning Order:  2
Combustible 1 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 2 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 3 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 4 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 5 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 6 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 7 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 8 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 9 Fuel Mass (lbm):
              Surface Area (ft2):

/* ********** USER DEFINED FUELS ********** */

/* ********** USER DEFINED MATERIALS ********** */

/* ********** FIRE COMPARTMENT DATA ********** */

  Length (ft):  16.0
  Width (ft):  12.5
  Height (ft):12.0
  Ceiling Thickness (ft):  1.0
  Wall Thickness (ft):  1.0
  Floor Thickness (ft):  1.0
  Ceiling Material:  1
  Wall Material:  1
  Floor Material:  1
  Number of Additional Flow Paths:  0
  Compartment Temperature (F):  60.0
  Compartment Pressure (in w.g.):  -0.55001
  Inlet Vent Elevation (ft):  2.0
  Outlet Vent Elevation (ft):  10.5
  Flame Base Elevation:  0.00
  Floor Temperature (F):  60.0
  Ceiling Temperature (F):  60.0
  Wall Temperature (F):  60.0
/* ********** ADDITIONAL FLOW PATHS ********** */

Number of Flow Paths:  0
```

FP VERSION 1.12

FILE: samp_2a.doc

/* ********** RUN CONTROL DATA ********** */

Run Control Option: ST
Initial Output Time (s): 0.0
Time between Outputs (s): 0.1
Last Output Time (s): 300.0
No. Special Output Times (s): 0
  First:
  Second:
  Third:
  Fourth:
  Fifth:
Max. Iterations:
Convergence Criterion:
Particle Deposition: N
Particle Entrainment: N
Initial Pressure Input:
Initial Temperature Input:
Buoyancy Term:

/* ********** AMBIENT CONDITIONS ********** */

Pressure (psia): 14.696
Temperature (F): 60.0

/* ********** BOUNDARY NODES ********** */

Number of Boundary Nodes: 4

Description: INLET BOUNDARY
  Node Number: 1
  Node Type: 0
  Initial Pressure (in w.g.): 0.0
  Pressure Function I.D.:
  Initial Temperature (F): 60.0
  Temperature Function I.D.:
  Elevation (ft): 0.0

Description: FIRE INLET
  Node Number: 2
  Node Type: 1
  Initial Pressure (in w.g.): -0.5001867
  Pressure Function I.D.: 0
  Initial Temperature (F): 60.0
  Temperature Function I.D.: 0
  Elevation (ft): 0.0

Description: FIRE OUTLET
Node Number: 3
Node Type: 1
Initial Pressure (in w.g.): -0.5001867
Pressure Function I.D.: 0
Initial Temperature (F): 60.0
Temperature Function I.D.: 0
Elevation (ft): 0.0

Description: EXHAUST BOUNDARY
Node Number: 6
Node Type: 0
Initial Pressure (in w.g.): -1.0
Pressure Function I.D.:
Initial Temperature (F): 60.0
Temperature Function I.D.:
Elevation (ft): 0.0

/* ********** ROOMS ********** */

Number of Rooms: 2

Description: EXHAUST DUCT NODE
Node Number: 4
Volume (ft3): 3.14
Energy Function Number:
Mass Function Number:
Pressure Function Number:
Temperature Function Number:
Initial Energy (kw):
Initial Mass (lbm/hr):
Initial Pressure (in w.g.):
Initial Temperature (F): 60.0
Flow Area (ft2): 3.14
No. Particulate Source Functions: 0
No. Gas Source Functions: 0
Gravitational Settling Flag:
Elevation (ft): 0.0
Width (ft):

Description: EXHAUST DUCT NODE
Node Number: 5
Volume (ft3): 3.14
Energy Function Number:
Mass Function Number:
Pressure Function Number:
Temperature Function Number:
Initial Energy (kw):
Initial Mass (lbm/hr):
Initial Pressure (in w.g.):
Initial Temperature (F): 60.0

```
  Flow Area (ft2):  3.14
  No. Particulate Source Functions:  0
  No. Gas Source Functions:  0
  Gravitational Settling Flag:
  Elevation (ft):  0.0
  Width (ft):

/* ********** BRANCHES AND DAMPERS ********** */

Number of Branches:  4
Number of Control Dampers:  0

Description:  INLET DAMPER
  Branch Number:  1
  Upstream Node Number:  1
  Downstream Node Number:  3
  Initial Flow (cfm):  750.0
  Flow Area (ft2):  3.14
  Duct Length (ft):  10.0
  Component Type:  V
  Pressure Differential (in w.g.):
  Blower Curve I.D.:
  Forward Resistance Coefficient:  1.60534
  Reverse Resistance Coefficient:  1.60534
  Filter Type:
  Duct Height (ft):
  Floor Area (ft):
  Heat Transfer Option:
  Roughness Height (m):
  Bend Angle (rad):
  Bend Radius (m):
  Drag Coefficient Factor:
  Shape Indicator:

Description:  EXHAUST DUCT
  Branch Number:  2
  Upstream Node Number:  2
  Downstream Node Number:  4
  Initial Flow (cfm):  750.0
  Flow Area (ft2):  3.14
  Duct Length (ft):  8.0
  Component Type:  D
  Pressure Differential (in w.g.):
  Blower Curve I.D.:
  Forward Resistance Coefficient:  1.58421
  Reverse Resistance Coefficient:  1.58421
  Filter Type:
  Duct Height (ft):
  Floor Area (ft):
  Heat Transfer Option:  0
  Roughness Height (m):
```

```
   Bend Angle (rad):
   Bend Radius (m):
   Drag Coefficient Factor:
   Shape Indicator:

 Description:  HEPA FILTER
   Branch Number:  3
   Upstream Node Number:  4
   Downstream Node Number:  5
   Initial Flow (cfm):  750.0
   Flow Area (ft2):  3.14
   Duct Length (ft):  1.0
   Component Type:  F
   Pressure Differential (in w.g.):  0.70
   Blower Curve I.D.:
   Forward Resistance Coefficient:
   Reverse Resistance Coefficient:
   Filter Type:  1
   Duct Height (ft):
   Floor Area (ft):
   Heat Transfer Option:
   Roughness Height (m):
   Bend Angle (rad):
   Bend Radius (m):
   Drag Coefficient Factor:
   Shape Indicator:

 Description:  EXHAUST BLOWER
   Branch Number:  4
   Upstream Node Number:  5
   Downstream Node Number:  6
   Initial Flow (cfm):  750.0
   Flow Area (ft2):  1.0
   Duct Length (ft):  1.0
   Component Type:  B
   Pressure Differential (in w.g.):
   Blower Curve I.D.:  1
   Forward Resistance Coefficient:
   Reverse Resistance Coefficient:
   Filter Type:
   Duct Height (ft):
   Floor Area (ft):
   Heat Transfer Option:
   Roughness Height (m):
   Bend Angle (rad):
   Bend Radius (m):
   Drag Coefficient Factor:
   Shape Indicator:

 /* ********** FILTERS ********** */
```

```
/* ********** BURNING LIQUIDS ********** */

Number of Burning Liquids:  0

/* ********** BURNING SOLIDS ********** */

Number of Burning Solids:  0

/* ********** HEATED SURFACES ********** */

Number of Heated Surfaces:  0

/* ********** BURNING METALS ********** */

Number of Burning Metals:  0

/* ********** FIRE SOURCE DATA ********** */

Ignition Energy Flag:  0
  0=Burning Order
  1=Ignition Energy
  2=Burning Rate

Maximum Burning Order:  1

Burning Order:  1
Combustible 1 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 2 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 3 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 4 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 5 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 6 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 7 Fuel Mass (lbm):  2.0
              Surface Area (ft2):  5.0
Combustible 8 Fuel Mass (lbm):
              Surface Area (ft2):
Combustible 9 Fuel Mass (lbm):
              Surface Area (ft2):

/* ********** USER DEFINED FUELS ********** */

/* ********** USER DEFINED MATERIALS ********** */

/* ********** FIRE COMPARTMENT DATA ********** */
```

```
Number of Filter Types:  1

Filter Type Number:  1
  Efficiency:  0.9
  Plugging Factor:
  Laminar Factor:
  Turbulent Factor:

/* ********** PARTICULATE SPECIES ********** */

Number of Particulate Species:  0

/* ********** GAS SPECIES ********** */

Number of Gas Species:  0

/* ********** BLOWER CURVES ********** */

Number of Blower Curves:  1

  No. Points in Blower Curve 1:  4
    Flow(cfm),Head(in w.g.)
    -8000.0,8.0
    0.0,1.8
    1200.0,1.5278
    6000.0,0.0

/* ********** PRESSURE FUNCTIONS ********** */

Number of Pressure Functions:  0

/* ********** TEMPERATURE FUNCTIONS ********** */

Number of Temperature Functions:  0

/* ********** ENERGY FUNCTIONS ********** */

Number of Energy Functions:  0

/* ********** MASS FUNCTIONS ********** */

Number of Mass Functions:  0

/* ********** PARTICULATE SPECIES FUNCTIONS ********** */

Number of Particulate Species Functions:  0

/* ********** GAS SPECIES FUNCTIONS ********** */

Number of Gas Species Functions:  0
```

```
/* ********** TIME DOMAINS ********** */

Time Domain:  1
  Dtmax (s):  0.01
  Tend (s):  1.0
  Edint (s):  1.0

Time Domain:  2
  Dtmax (s):  0.1
  Tend (s):  300.0
  Edint (s):  1.0

/* ********************************** */
/* ********** FIRIN MODULE ********** */
/* ********************************** */

IFIRIN flag:  0

Inlet Node Number:  2
Outlet Node Number:  3
Third Node Number  0
Inlet Branch Number:  1
Inlet Branch Diameter (ft):  2.0
Outlet Branch Number:  2
Outlet Branch Diameter (ft):  2.0
Third Branch Number:
Third Branch Diameter (ft):
Third Branch Elevation (ft):
Third Branch Flow Direction:

/* ********** RUN CONTROL DATA ********** */

Fire Duration (s):  1000.0
Fire Start Time (s):  0.0
Print Interval (time steps):  20

/* ********** HEAT SINKS ********** */

Number of Heat Sinks:  0

/* ********** POWDER CONTAINERS ********** */

Number of Powder Containers:  0

/* ********** CLOSED LIQUID CONTAINERS ********** */

Number of Closed Liquid Containers:  0

/* ********** OPEN LIQUID CONTAINERS ********** */

Number of Open Liquid Containers:  0
```

```
  Length (ft):  27.0
  Width (ft):  17
  Height (ft):15
  Ceiling Thickness (ft):  1.0
  Wall Thickness (ft):  1.0
  Floor Thickness (ft):  1.0
  Ceiling Material:  1
  Wall Material:  1
  Floor Material:  1
  Number of Additional Flow Paths:  0
  Compartment Temperature (F):  60.0
  Compartment Pressure (in w.g.):  -0.50018
  Inlet Vent Elevation (ft):  2.0
  Outlet Vent Elevation (ft):  13.0
  Flame Base Elevation:  0.0
  Floor Temperature (F):  60.0
  Ceiling Temperature (F):  60.0
  Wall Temperature (F):  60.0
/* ********** ADDITIONAL FLOW PATHS ********** */

Number of Flow Paths:  0
```

Appendix C

Fastlite documentation files

AST Version 2.2.1 62 WATTS ST FIRE

ta file is TMPRN1 (Checksum 00000000)

ERVIEW

mpartments	Doors, ...	Ceil. Vents, ...	MV Connects
2	4	0	0

mulation me)	Print Interval (s)	History Interval (s)	Restart Interval (s)
3000	10	30	0

iling jet is on for all

MPARTMENTS

mpartment	Width (m)	Depth (m)	Height (m)	Ceiling Height (m)	Floor Height (m)
1	12.80	6.10	2.53	2.53	0.00
2	1.22	3.05	9.14	9.14	0.00

NT CONNECTIONS

izontal Natural Flow Connections (Doors, Windows, ...)

om partment	To Compartment	Vent Number	Width (m)	Sill Height (m)	Soffit Height (m)
1	2	1	0.91	0.00	0.00
1	Outside	1	1.32	1.10	1.14
2	Outside	1	3.05	8.87	9.10
2	Outside	2	0.91	0.00	2.13

re are no vertical natural flow connections

RMAL PROPERTIES

partment	Ceiling	Wall	Floor
1	GYPSUM	GYPSUM	HARDWOOD
2	GYPSUM	GYPSUM	HARDWOOD

rmal data base used: THERMAL.DF

e	Conductivity	Specific heat	Density	Thickness	Emissivity

PSUM	0.160	900.	790.	1.600E-02	0.900
RDWOOD	0.160	1.255E+03	720.	1.900E-02	0.900

RES

mpartment: 1
re Type: Constrained
sition (x,y,z): 2.15 1.65 0.00
lative Humidity: 50.0
wer O2 Limit: 10.00
rolysis Temp.: 293.

Time (s)	Fmass (kg/s)	Hcomb (J/kg)	Fqdot (W)	C/CO2 (m)	CO/CO2 (kg/kg)	H/C (kg/kg)
0.	1.28E-03	1.95E+07	2.50E+04	3.00E-02	3.00E-02	8.00E-02
500.	1.28E-03	1.95E+07	2.50E+04	3.00E-02	3.00E-02	8.00E-02
533.	6.55E-04	1.95E+07	1.28E+04	3.00E-02	3.00E-02	8.00E-02
566.	2.62E-03	1.95E+07	5.11E+04	3.00E-02	3.00E-02	8.00E-02
599.	5.89E-03	1.95E+07	1.15E+05	3.00E-02	3.00E-02	8.00E-02
632.	1.05E-02	1.95E+07	2.04E+05	3.00E-02	3.00E-02	8.00E-02
665.	1.64E-02	1.95E+07	3.19E+05	3.00E-02	3.00E-02	8.00E-02
698.	2.36E-02	1.95E+07	4.60E+05	3.00E-02	3.00E-02	8.00E-02
731.	3.21E-02	1.95E+07	6.26E+05	3.00E-02	3.00E-02	8.00E-02
764.	4.19E-02	1.95E+07	8.17E+05	3.00E-02	3.00E-02	8.00E-02
800.	5.41E-02	1.95E+07	1.06E+06	3.00E-02	3.00E-02	8.00E-02
000.	5.41E-02	1.95E+07	1.06E+06	3.00E-02	3.00E-02	8.00E-02
011.	4.29E-02	1.95E+07	8.36E+05	3.00E-02	3.00E-02	8.00E-02
022.	3.29E-02	1.95E+07	6.42E+05	3.00E-02	3.00E-02	8.00E-02
033.	2.43E-02	1.95E+07	4.74E+05	3.00E-02	3.00E-02	8.00E-02
044.	1.70E-02	1.95E+07	3.31E+05	3.00E-02	3.00E-02	8.00E-02
055.	1.10E-02	1.95E+07	2.14E+05	3.00E-02	3.00E-02	8.00E-02
066.	6.25E-03	1.95E+07	1.22E+05	3.00E-02	3.00E-02	8.00E-02
077.	2.86E-03	1.95E+07	5.58E+04	3.00E-02	3.00E-02	8.00E-02
088.	7.79E-04	1.95E+07	1.52E+04	3.00E-02	3.00E-02	8.00E-02
100.	0.00E+00	1.95E+07	0.00E+00	3.00E-02	3.00E-02	8.00E-02

e = 0.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	293.1	293.1	2.5	1.282E-03	2.500E+04	1.47	0.000E+00
2	293.1	293.1	9.1	0.000E+00	0.000E+00	-0.879	0.000E+00
tside					0.000E+00		

e = 10.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)

1	310.2	293.1	2.4	1.282E-03	2.500E+04	0.381	106.
2	292.2	290.6	9.1	0.000E+00	0.000E+00	-0.657	0.000E+00
utside					0.000E+00		

me = 20.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.1	293.1	2.3	1.282E-03	2.500E+04	0.261	99.0
2	291.8	289.0	9.1	0.000E+00	0.000E+00	-0.516	0.000E+00
utside					0.000E+00		

ne = 30.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	308.2	293.1	2.2	1.282E-03	2.500E+04	0.186	92.6
2	291.4	287.9	9.1	0.000E+00	0.000E+00	-0.423	0.000E+00
utside					0.000E+00		

he = 40.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	307.7	293.1	2.1	1.282E-03	2.500E+04	0.114	89.6
2	291.1	287.2	9.1	0.000E+00	0.000E+00	-0.358	0.000E+00
tside					0.000E+00		

e = 50.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	307.6	293.1	1.9	1.282E-03	2.500E+04	4.692E-02	88.6
2	290.9	286.7	9.1	0.000E+00	0.000E+00	-0.312	0.000E+00
tside					0.000E+00		

e = 60.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)

1	307.5	293.1	1.8	1.282E-03	2.500E+04	-1.103E-02	88.5
2	290.6	286.3	9.1	0.000E+00	0.000E+00	-0.278	0.000E+00
utside					0.000E+00		

ne = 70.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	307.6	293.1	1.8	1.282E-03	2.500E+04	-6.080E-02	88.7
2	290.4	286.0	9.1	0.000E+00	0.000E+00	-0.252	0.000E+00
utside					0.000E+00		

ne = 80.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	307.7	293.1	1.7	1.282E-03	2.500E+04	-0.104	89.2
2	290.2	285.7	9.1	0.000E+00	0.000E+00	-0.232	0.000E+00
tside					0.000E+00		

e = 90.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	307.7	293.1	1.6	1.282E-03	2.500E+04	-0.140	89.8
2	290.0	285.6	9.1	0.000E+00	0.000E+00	-0.216	0.000E+00
tside					0.000E+00		

e = 100.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	307.8	293.1	1.5	1.282E-03	2.500E+04	-0.172	90.5
2	289.8	285.4	9.1	0.000E+00	0.000E+00	-0.204	0.000E+00
tside					0.000E+00		

e = 110.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)

1	307.9	293.1	1.5	1.282E-03	2.500E+04	-0.199	91.2
2	289.7	285.3	9.1	0.000E+00	0.000E+00	-0.194	0.000E+00
utside					0.000E+00		

me = 120.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	308.1	293.0	1.4	1.282E-03	2.500E+04	-0.222	91.9
2	289.5	285.2	9.1	0.000E+00	0.000E+00	-0.185	0.000E+00
utside					0.000E+00		

me = 130.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	308.2	293.0	1.4	1.282E-03	2.500E+04	-0.243	92.6
2	289.4	285.1	9.1	0.000E+00	0.000E+00	-0.178	0.000E+00
ıtside					0.000E+00		

ıe = 140.0 seconds.

ıpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	308.3	293.0	1.3	1.282E-03	2.500E+04	-0.262	93.3
2	289.3	285.1	9.1	0.000E+00	0.000E+00	-0.172	0.000E+00
tside					0.000E+00		

e = 150.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	308.4	293.0	1.3	1.282E-03	2.500E+04	-0.278	94.0
2	289.2	285.0	9.1	0.000E+00	0.000E+00	-0.167	0.000E+00
tside					0.000E+00		

e = 160.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)

1	308.5	293.0	1.2	1.282E-03	2.500E+04	-0.292	94.7
2	289.0	285.0	9.1	0.000E+00	0.000E+00	-0.163	0.000E+00
itside					0.000E+00		

ıe = 170.0 seconds.

ıpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	308.6	293.0	1.2	1.282E-03	2.500E+04	-0.305	95.4
2	288.9	284.9	9.1	0.000E+00	0.000E+00	-0.159	0.000E+00
tside					0.000E+00		

e = 180.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	308.7	293.0	1.1	1.282E-03	2.500E+04	-0.316	96.1
2	288.9	284.9	9.1	0.000E+00	0.000E+00	-0.156	0.000E+00
tside					0.000E+00		

e = 190.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	308.8	293.0	1.1	1.282E-03	2.500E+04	-0.341	96.8
2	288.8	284.9	9.1	0.000E+00	0.000E+00	-0.152	0.000E+00
tside					0.000E+00		

e = 200.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
	308.9	293.0	1.1	1.282E-03	2.500E+04	-0.369	97.4
2	288.7	284.8	9.1	0.000E+00	0.000E+00	-0.150	0.000E+00
tside					0.000E+00		

e = 210.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)

1	309.0	293.0	1.0	1.282E-03	2.500E+04	-0.395	98.1
2	288.6	284.8	9.1	0.000E+00	0.000E+00	-0.147	0.000E+00
utside					0.000E+00		

me = 220.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.1	293.0	1.0	1.282E-03	2.500E+04	-0.419	98.7
2	288.5	284.8	9.1	0.000E+00	0.000E+00	-0.145	0.000E+00
utside					0.000E+00		

me = 230.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.2	293.0	0.99	1.282E-03	2.500E+04	-0.443	99.3
2	288.5	284.7	9.1	0.000E+00	0.000E+00	-0.143	0.000E+00
utside					0.000E+00		

me = 240.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.3	293.0	0.96	1.282E-03	2.500E+04	-0.465	99.9
2	288.4	284.7	9.1	0.000E+00	0.000E+00	-0.141	0.000E+00
tside					0.000E+00		

e = 250.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.4	293.0	0.94	1.282E-03	2.500E+04	-0.486	101.
2	288.3	284.7	9.1	0.000E+00	0.000E+00	-0.139	0.000E+00
tside					0.000E+00		

e = 260.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)

1	309.4	293.0	0.91	1.282E-03	2.500E+04-0.506	101.
2	288.3	284.7	9.1	0.000E+00	0.000E+00-0.137	0.000E+00
utside					0.000E+00	

me = 270.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.5	293.0	0.89	1.282E-03	2.500E+04	-0.525	102.
2	288.2	284.7	9.1	0.000E+00	0.000E+00	-0.136	0.000E+00
ıtside					0.000E+00		

ne = 280.0 seconds.

npartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.6	293.1	0.87	1.282E-03	2.500E+04	-0.543	102.
2	288.2	284.7	9.1	0.000E+00	0.000E+00	-0.134	0.000E+00
tside					0.000E+00		

e = 290.0 seconds.

partment	Upper Temp.	Lower Temp.	Inter. Height	Pyrol Rate	Fire Size	Pressure	Ambient (K)
1	309.7	293.1	0.85	1.282E-03	2.500E+04	-0.560	103.
2	288.1	284.6	9.1	0.000E+00	0.000E+00	-0.133	0.000E+00
tside					0.000E+00		

e = 300.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.8	293.1	0.83	1.282E-03	2.500E+04	-0.577	103.
2	288.1	284.6	9.1	0.000E+00	0.000E+00	-0.132	0.000E+00
tside					0.000E+00		

e = 310.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	309.9	293.1	0.81	1.282E-03	2.500E+04	-0.593	104.

2	288.0	284.6	9.1	0.000E+00	0.000E+00	-0.131	0.000E+00
utside					0.000E+00		

ne = 320.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.0	293.1	0.79	1.282E-03	2.500E+04	-0.609	105.
2	288.0	284.6	9.1	0.000E+00	0.000E+00	-0.129	0.000E+00
utside					0.000E+00		

ne = 330.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.0	293.1	0.78	1.282E-03	2.500E+04	-0.624	105.
2	287.9	284.6	9.1	0.000E+00	0.000E+00	-0.128	0.000E+00
utside					0.000E+00		

ne = 340.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.1	293.2	0.76	1.282E-03	2.500E+04	-0.638	106.
2	287.9	284.6	9.1	0.000E+00	0.000E+00	-0.127	0.000E+00
tside					0.000E+00		

e = 350.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.2	293.2	0.74	1.282E-03	2.500E+04	-0.652	106.
2	287.9	284.6	9.1	0.000E+00	0.000E+00	-0.126	0.000E+00
tside					0.000E+00		

e = 360.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.3	293.2	0.73	1.282E-03	2.500E+04	-0.666	107.

2	287.8	284.5	9.1	0.000E+00	0.000E+00	-0.125	0.000E+00
tside					0.000E+00		

e = 370.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.4	293.2	0.71	1.282E-03	2.500E+04	-0.679	107.
2	287.8	284.5	9.1	0.000E+00	0.000E+00	-0.124	0.000E+00
tside					0.000E+00		

e = 380.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.4	293.3	0.70	1.282E-03	2.500E+04	-0.692	108.
2	287.7	284.5	9.1	0.000E+00	0.000E+00	-0.123	0.000E+00
tside					0.000E+00		

e = 390.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
	310.5	293.3	0.69	1.282E-03	2.500E+04	-0.704	108.
	287.7	284.5	9.1	0.000E+00	0.000E+00	-0.122	0.000E+00
side					0.000E+00		

= 400.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
	310.6	293.3	0.67	1.282E-03	2.500E+04	-0.716	109.
	287.7	284.5	9.1	0.000E+00	0.000E+00	-0.121	0.000E+00
side					0.000E+00		

= 410.0 seconds.

artment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
	310.7	293.4	0.66	1.282E-03	2.500E+04	-0.728	109.

2	287.6	284.5	9.1	0.000E+00	0.000E+00	-0.121	0.000E+00
utside					0.000E+00		

ne = 420.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.7	293.4	0.65	1.282E-03	2.500E+04	-0.739	110.
2	287.6	284.5	9.1	0.000E+00	0.000E+00	-0.120	0.000E+00
utside					0.000E+00		

ne = 430.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.8	293.4	0.64	1.282E-03	2.500E+04	-0.750	110.
2	287.6	284.5	9.1	0.000E+00	0.000E+00	-0.119	0.000E+00
tside					0.000E+00		

e = 440.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.9	293.5	0.63	1.282E-03	2.500E+04	-0.761	111.
2	287.5	284.5	9.1	0.000E+00	0.000E+00	-0.118	0.000E+00
tside					0.000E+00		

e = 450.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	311.0	293.5	0.62	1.282E-03	2.500E+04	-0.772	111.
2	287.5	284.5	9.1	0.000E+00	0.000E+00	-0.117	0.000E+00
tside					0.000E+00		

e = 460.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	311.0	293.6	0.60	1.282E-03	2.500E+04	-0.782	112.

2	287.5	284.5	9.1	0.000E+00	0.000E+00	-0.117	0.000E+00
tside					0.000E+00		

e = 470.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	311.1	293.6	0.59	1.282E-03	2.500E+04	-0.792	112.
2	287.4	284.4	9.1	0.000E+00	0.000E+00	-0.116	0.000E+00
tside					0.000E+00		

e = 480.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	311.2	293.6	0.58	1.282E-03	2.500E+04	-0.803	113.
2	287.4	284.4	9.1	0.000E+00	0.000E+00	-0.115	0.000E+00
tside					0.000E+00		

e = 490.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	311.2	293.7	0.57	1.282E-03	2.500E+04	-0.812	113.
2	287.4	284.4	9.1	0.000E+00	0.000E+00	-0.115	0.000E+00
tside					0.000E+00		

e = 500.0 seconds.

partment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
	311.3	293.7	0.56	1.282E-03	2.500E+04	-0.822	114.
	287.3	284.4	9.1	0.000E+00	0.000E+00	-0.114	0.000E+00
side					0.000E+00		

= 510.0 seconds.

artment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
	311.2	293.8	0.55	1.092E-03	2.129E+04	-0.868	113.

2	287.3	284.4	9.1	0.000E+00	0.000E+00	-0.113	0.000E+00
utside					0.000E+00		

me = 520.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	311.0	293.8	0.55	9.018E-04	1.758E+04	-0.916	112.
2	287.3	284.4	9.1	0.000E+00	0.000E+00	-0.113	0.000E+00
utside					0.000E+00		

me = 530.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.6	293.8	0.54	7.117E-04	1.388E+04	-1.03	109.
2	287.3	284.4	9.1	0.000E+00	0.000E+00	-0.112	0.000E+00
utside					0.000E+00		

me = 540.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.2	293.8	0.54	1.071E-03	2.089E+04	-0.848	106.
2	287.2	284.4	9.1	0.000E+00	0.000E+00	-0.111	0.000E+00
utside					0.000E+00		

me = 550.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	310.5	293.9	0.53	1.666E-03	3.249E+04	-0.367	108.
2	287.2	284.4	9.1	0.000E+00	0.000E+00	-0.111	0.000E+00
utside					0.000E+00		

me = 560.0 seconds.

mpartment	Upper Temp. (K)	Lower Temp. (K)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	311.4	293.9	0.51	2.261E-03	4.410E+04	0.797	114.

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